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EFFECTS OF TRAINING  
ON THE OXYGEN CONSUMPTION OF  
THREE TYPES OF MUSCULAR CONTRACTION



BY  
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A THESIS  
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THE UNIVERSITY OF ALBERTA  
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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "Effects of Training on the Oxygen Consumption of Three Types of Muscular Contraction", submitted by Ian Frank Jobling in partial fulfilment of the requirements for the degree of Master of Arts.



## ABSTRACT

It was the purpose of this thesis to determine the effects of training on the relationship between the oxygen consumption of concentric, eccentric, and isometric muscular contractions.

Thirty-three male freshmen of The University of Alberta participated in, and completed a training and testing programme over a duration of nine weeks. Each subject was trained and tested as a member of the particular contraction group to which he had been assigned. Each subject participated in eighteen training sessions at an average of three sessions weekly. The initial number of contractions for each subject was six, each of six-seconds duration and this number increased by three after every third training session until a total of eighteen contractions was reached.

During the testing sessions, the expired air of each subject was collected at various intervals to determine the oxygen consumed during a series of contractions. The force exerted by each subject during contractions was recorded and calculated in terms of average force. The above measurements were used to ascertain the value of Oxygen Consumption per pound-second.

Statistical analysis of these results of Oxygen Consumption per pound-second revealed that the means of the concentric, eccentric, and isometric contraction groups were significantly different from each other ( $P < 0.01$ ). The eccentric contraction group required the least in terms of oxygen consumption per pound-second, the concentric group requiring the most, and the isometric group requiring less than concentric



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and more than eccentric. The training programme did not significantly affect the Oxygen Consumption per pound-second of any contraction group. The effect of interaction between the contraction groups and the test periods was not significant in respect to Oxygen Consumption per pound-second. Results showed that oxygen consumption did not necessarily increase with an increase in strength, and this applied to all contraction groups.

The results indicated that the eccentric contraction training method was the most efficient of the three types of contraction since this method required the least amount in Oxygen Consumption per pound-second for the most amount in Average Force in pounds per second.



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## CHAPTER I

### STATEMENT OF THE PROBLEM

#### Introduction

The human body, through its arrangement of agonist and antagonist muscles, is designed to perform work of all kinds through concentric (positive work), isometric (static work), or eccentric (negative work) muscular contractions. The notions of positive and negative work may be illustrated in the practical example of a person climbing a ladder. Ascending the ladder, the leg extensors shorten and perform positive work against gravity; but during descent, those same muscles are stretched while actively resisting the gravitational pull and are performing negative work (3). A similar effect can be illustrated in ascending and descending stairs (10) or, for the arms, climbing up and down a rope (6).

When muscles shorten in contraction and do work they liberate extra energy (14,15) and this extra energy consists of two parts, the heat of shortening and the work itself (22,24). Contracting muscles resist stretch strongly (6) with a force which may be twice that of maximal isometric tetanus (22,23,38). Investigators have found that in a muscle stretched during a contraction, part of the work done in the muscle disappears (1,2) and there is a reduction in the energy liberated in the muscle itself (23).

Practical studies of different contractions have been conducted (3,4,6,18) and it has been found that positive work always costs more in terms of oxygen consumption than negative work. Other practical



studies (7,42,43) support the view that isometric contractions or static work costs less in terms of oxygen consumption than concentric contractions or positive work.

Various methods of training to develop strength have been investigated especially since Hettinger and Muller (19) reported that muscular strength increased five per cent per week as a result of one daily isometric contraction held for six seconds at two-thirds maximum tension. Since that report, many studies (5,9,28,29,30,31,35,36,40,45) have been conducted comparing the strength increases as a result of isometric or isotonic training.

Research in comparing the relationships of training programmes using different types of muscular contraction with oxygen cost has been lacking. A factor of training is to enable an individual to undertake a particular task at minimal physiological cost to himself, or "to bring to a maximum the amount of work which he can perform for a given and defined physiological cost."(17) Any increase in the efficiency of muscular contraction (the ratio between useful work and energy expenditure (24)) must come from a more economical and efficient use of the body. A study of the effects of training using different types of muscular contraction on oxygen consumption gives an estimation of that economy and efficiency.

### The Problem

The purpose of this study is to determine the relationship between the oxygen consumption of concentric, eccentric and isometric muscular contractions before, during and after a strength training programme.



The data available also permit investigation of the following sub-problem: whether or not oxygen consumption increases with an increase in strength within the three contraction groups.

In the problem, the null hypotheses are:

1. That the means of the three groups shall be equal.

$$H_o: u_I = u_C = u_E$$

2. That the means of the three periods shall be equal.

$$H_o: u_1 = u_2 = u_3$$

3. That the interaction between the groups and the periods is not significant.  $H_o$ : Interaction not significant.

#### Delimitations of the Study

1. The study is delimited to 33 subjects<sup>1</sup> selected randomly from a population of male freshman students from all faculties except Physical Education and Engineering at The University of Alberta, Edmonton.

2. The study is delimited in the number of muscle groups involved. The muscles to be used in the experiment are the extensor muscles of the hip - gluteus maximus, biceps femoris, semitendinosus and semi-membranosus; the extensor muscles of the knee - rectus femoris, vastus lateralis, vastus intermedius and vastus medialis and the plantarflexor muscles of the ankles - gastrocnemius and soleus.

#### Definition of Terms

Oxygen Consumption. Oxygen consumption is the amount of excess oxygen consumed during an activity and recovery from that activity, that is,

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<sup>1</sup>The original number of subjects selected was 39 but 6 subjects failed to complete training and tests, and were not included in the data for statistical analysis.



total oxygen consumption minus resting oxygen consumption for an equivalent period of time (32).  $\text{Oxygen Consumption} = \text{oxygen used during work in A minutes} + \text{oxygen used during recovery in B minutes} - \text{resting oxygen in A} + \text{B minutes}$  (26). In this study the recovery period (B) is five minutes since subjects also rest a total of 75 seconds between contractions. A pilot study showed that subjects recovered adequately in a period of five minutes.

Concentric Contraction. A contraction during which the length of contracting muscle decreases. It also refers to positive work. In this experiment, the concentric contraction performed is a movement of the knee angle from 60 degrees flexion to 150 degrees flexion.

Eccentric Contraction. A contraction during which the length of contracting muscle increases. It also refers to negative work. In this experiment, the eccentric contraction performed is a movement of the knee angle from 150 degrees flexion to 60 degrees flexion.

Isometric Contraction. A contraction during which the length of contracting muscle neither decreases nor increases but remains the same. It also refers to static work. In this experiment, the isometric contraction is performed at a knee angle of 100 degrees flexion.

Resting Metabolism. Resting metabolism represents the amount of energy expended during inactivity (26). In this study, the distinction between resting metabolism and "basal metabolism", which is defined as the lowest energy necessary for mere existence (26), is important.



## CHAPTER II

### REVIEW OF THE LITERATURE

Structure and Chemistry of Muscle. Skeletal muscle consists of long cylindrical muscle fibres of dimensions varying between 10 to 100 microns in diameter and 1 millimetre to 4 centimetres in length (12). Each muscle fibre represents a single cell and consists of a mass of protoplasm called sarcoplasm in which long filaments known as myofibrils are embedded (32). A muscle fibre may contain up to 10 million filaments which are made of proteins called myosin and actin, and which are the contracting elements of the muscle (27). The sarcolemma or thin membrane covering the fibre insulates it from adjacent fibres so that stimulation occurs individually (32). A motor nerve penetrates each sarcolemma and through the motor end plate a nerve stimulus causes the fibre to contract (27). The muscle fibre contracts maximally for any given set of conditions, such as nutrition or temperature, or it does not contract at all - such being the all or none law of muscle contraction (12). The most accepted theory of contraction of the myofibril is the sliding movement of the actin and myosin filaments (32). Huxley (25) pictures the "two types of filaments being driven past each other, in the appropriate direction, by a stereo-specific interaction between the actin and myosin molecules which the filaments contain". The development of relative force between filaments depends upon the splitting of ATP by the actin-myosin system.

The energy for muscle contraction is obtained from a complex series of chemical reactions which are reversed during recovery (32).



The immediate source of energy for the contractile processes of the actin and myosin filaments of the myofibril is the break-down of "high energy compounds, adenosine triphosphate (ATP) to adenosine diphosphate (ADP) (32,27). The ultimate source of energy is the oxidation of foodstuffs for the re-synthesis of ATP (12,32). Creatine phosphate is necessary to act as an organic phosphate to supply energy for the re-synthesis of ATP (32). This energy for muscle contraction can be supplied by aerobic or anaerobic processes, however anaerobic contractions cannot continue beyond when an accumulation of lactic acid prevents it (27,12). When oxygen is present glycogen is broken down to pyruvic acid only, which then enters into the chemical process of the Krebs cycle and is reduced to carbon dioxide and water (27).

Energy Liberated in Muscle Contraction. Studies conducted by Fenn (14,15) using the sartorius muscle of the frog provided observations as to the amount of energy liberated in a muscular contraction. Fenn found that when a stimulated muscle shortened and performed work in lifting a weight, an extra amount of energy was mobilized which did not appear in an isometric contraction. The extra liberated energy is roughly proportional to work done, and does not appear in the muscle as heat. By using a weight too heavy for a contracting muscle to hold, Fenn showed that less energy was mobilized by the muscle when it was stretched during stimulation. Fenn concluded:

"Lengthening during the contraction period decreases the energy liberated. This is interpreted as meaning that when the work done by the muscle is negative, the excess energy is also negative." (15:394)



Hill (21) attempted to explain the observations of Fenn and considered the thermo-elastic phenomena which occur when a muscle contracts or relaxes. Feng (13) supported these considerations by observing that the stretched sartorius muscle of the frog was warmed when the initial stretching load was small, and it cooled when released. However, increasing the initial load completely reversed the results and Feng concluded that the thermo-elastic properties of a muscle depend on the initial load.

A later study by Hill (22) enabled further elaboration of Fenn's results. When a muscle shortens in a tetanically maintained contraction extra energy is liberated as "shortening heat", and as external mechanical work. The heat produced through shortening was found to be independent of the load, the work done, and the speed of shortening. In an eccentric contraction there was a negative heat of lengthening and Hill concluded that "the energy relations in lengthening are the converse of those in shortening and seem to be governed by the same rules." (22:193). Further studies by Abbott et.al. (1,2) confirmed these observations and several possibilities why a stretched muscle should give out less energy were considered. The investigators concluded that during an eccentric contraction the work is absorbed in reversing chemical processes which normally provide work when the muscle is able to shorten.

A study to obtain more detailed and convincing evidence of chemical reversal by applied stretch was conducted by Hill and Howarth (23). The investigators used the sartorii muscles of toads and the heat and tension of the contractions were recorded separately and simul-



taneously. It was found that contracting muscles resisted an applied stretch with a force twice that of maximal isometric tetanus. The results of the investigation confirmed the fact that "mechanical work applied to a contracting muscle by stretching it may reduce the net energy liberated by the muscle itself, either to nothing, or to an amount much less than that in a similar contraction without stretch." (23:182).

In 1960, Hill (24) reviewed the studies conducted since Fenn (14) which were concerned with the relationships between work and heat under various conditions of shortening, lengthening and tension. Stimulated muscle passes from a state of rest to one of activity and this transformation requires chemical change resulting in heat production (A). Further heat is produced when the muscle shortens ( $ax$ , where "a" is the amount of shortening and "x" is a constant of the dimensions of force) and the heat produced is proportional to the amount of shortening in the contractile component. Hill uses the term "overhead" for this heat produced from muscle activation, maintenance of stimuli, and shortening. The mechanical work a muscle performs (W) does not affect this overhead heat, but it appears in the equation: total energy by muscle =  $A + ax + W$ . Hill states:

"To get the greatest mechanical output from a given expenditure of chemical energy, the conditions must be adjusted to make  $(A + ax)/W$  as small as possible. But the "overhead" cost of contraction cannot be avoided, and this suggests that it may not really be "irreversibility" (in the thermodynamic sense) that limits the ratio of work done to energy used, but the nature of the machine itself. .... The muscle can perform mechanical work with an extra expenditure of energy no greater than the work itself." (24:898)



Hill confirmed the hypothesis set up previously (1) that the whole of the work on a stretched muscle under contraction disappears and does not reappear as heat. The degree of reversal of chemical reactions depends upon the amount of stretch or the amount of work applied and Hill concluded that "a stretch cannot reverse any chemical reaction except that of the actual contraction during which the stretch was applied." (24:899).

Oxygen Cost of Muscle Contractions. Abbott, et.al. (3) compared the oxygen consumption involved in performing positive work (concentric contractions) with that of negative work (eccentric contractions). Two bicycles were arranged in opposition and coupled by a chain so that when one cyclist pedaled forward (concentrically) the legs of the other cyclist absorbed the force and were driven backwards. This "back-pedaling was actually normal pedaling reversed so that the same muscles used in cycling contracted but instead of shortening they were forcibly stretched." For all experiments, though both cyclists did the same amount of work, less oxygen was consumed by the resisting subject than the subject pedaling forwards. The investigators found that the subject performing eccentrically was never as subjectively tired as the concentric performer. The investigators explained:

"The cyclist resisting the movement had stretches imposed on his muscles. An active muscle resists stretch with a tension greater than the isometric value under the same conditions of excitation: the area under the tension time curve is increased by imposed lengthening both for fused and for unfused tetani (Abbott, unpublished). The cyclist therefore can resist with a force equal to that exerted by the "forward cyclist" (whose muscles are shortening) with less fibres and/or with a lower frequency of excitation of the fibres." (3:387)



Hill (24) commented later that at the time of the cycling study researchers were not certain that stretching a muscle during contraction causes reversals of chemical processes. The partial reversal of chemical reactions played a substantial part in the lower oxygen consumption of the cyclist performing eccentrically. Abbott, et.al. concluded:

"Positive work always costs more than negative work. At a pedaling speed of 35 rev/min the ratio of oxygen consumptions for the two tasks was 3.7. This ratio increased with the speed of pedaling." (3:589)

Abbott and Bigland (4) conducted further investigations of negative work in which force and speed were varied independently. A bicycle ergometer was coupled by a belt from its fly wheel to pulleys of different sizes on the shaft of a constant speed motor which drove the bicycle backwards. Results showed that when the rate of negative work was increased at constant speed the rate of oxygen consumption increased rapidly, but when the rate of work was increased at constant force by varying the speed of pedaling, the oxygen consumption remained relatively constant. The investigators explained these results:

"In shortening, the faster an active muscle contracts the smaller is the tension it can exert (22); but when it is forcibly stretched the use in tension above the isometric value, except at the very lowest speeds of stretch, depends only on the distance moved and not on the speed of movement (3)". (4:323)

Asmussen (6) used two bicycles, one "uphill" to measure positive work, and the other "downhill" to measure negative work. For the bicycle for negative work an extra cogwheel was fitted to reverse the movements of the pedals thus enabling the rider to perform eccentric muscle contractions. The results indicated that negative work costs



less than positive work and the ratio cost of positive work to cost of negative work increased as speed of movement increased. Asmussen states that this increased ratio was due to the decreasing cost of negative work as the speed of pedaling increases.

Passmore and Durnin (34) compiled and reviewed literature pertaining to studies of human energy expenditure of various activities although no distinction is made between activities which require isometric, eccentric or concentric contractions.

Tuttle and Horvath (43) compared dynamic work on a bicycle ergometer with that of isometric work in squeezing a grip dynamometer. The oxygen consumption for performing these activities was different, (as determined by oxygen debt) with the isometric activity requiring less oxygen consumption than concentric activity.

Metabolic cost of isometric exercise in relation to work load was studied by Clarke (7) and compared with dynamic work. Subjects held various weights against the thighs in such a position that the muscles exerting force were mainly the quadriceps. Clarke found that the oxygen consumption during static work was less than that required during dynamic work (work on a bicycle ergometer) but there was a larger oxygen debt. Such results are consistent with those of Royce (39) who found that an occluded muscle in isometric contraction has virtually no circulation where the tension is above twenty-six kilograms, so the cost of work needs to be met by a relatively larger oxygen debt.

Asmussen (6) states that during isometric contractions the blood flow to muscles becomes partly or totally blocked and the muscles have to depend on the energy stores within the muscle fibres. So, for



long contractions anaerobic processes supply the necessary energy. Asmussen also states that the oxygen cost of negative work may be less than one-tenth the cost of the same amount of positive work.

Hesser (18) studied the energy cost of rapidly alternating positive and negative work by observing male and female subjects ascending and descending stairs, and comparing the results with the energy cost of continuous positive work. It was found that the ratio of oxygen costs for the positive and negative works was approximately 8:1 at a speed of 88 steps per minute and 5:1 at 160 steps per minute.

Sharkey (42) made physiological comparisons of static and concentric contractions of the legs and found that oxygen consumption during the static contraction was considerably less than that of the dynamic contraction.

#### Comparison of Strength Development from Isotonic or Isometric Contractions.

DeLorme (10) outlined exercise of a dynamic type using heavy resistance and few repetitions to build up strength. In 1948 DeLorme (11) proposed that fewer repetitions per training session resulted in the same increase in strength. DeLorme's "progressive resistance exercises" comprised three sets of ten contractions per day.

In 1953, Hettinger and Muller (19) published results of experiments on training using static or isometric contractions. Using the flexor and extensor muscles of the forearm, subjects pulled and held a predetermined amount of tension against a spring scale. The conclusions from these experiments were later modified by Muller (33) and Hettinger (20). Some conclusions were:



"... Maintaining a maximum isometric contraction for only one or two seconds is sufficient to provide a training stimulus. When the contraction involves only two-thirds of the maximum strength, it should be maintained approximately four to six seconds, and so on. On the other hand, muscle contractions of very short duration have no effect (20:28). ... It was found that the maximum increase in muscle strength was obtained with one training stimulus per day". (20:29)

Many investigations have been conducted on the strength increases from isometric training following these findings of Hettinger and Muller. A brief review of comparative studies of strength training using isometric and dynamic muscular contractions shall be given.

Lorback (29) reported that increases in the strength by a single contraction held for six seconds at two-thirds maximal three times a week for eight weeks were statistically significant. This increase proved as effective as that increase resulting from performing repeated exercise against an overload of weights.

Darcus and Salter (9) conducted experiments using isotonic and isometric contractions on movements of the lower arm and found that both types of training resulted in increases of strength with dynamic training producing greater improvement.

Salter (40) found that repeated sessions of isometric and isotonic contractions on the training of supination of the left hand at the rate of either two or fifteen per minute resulted in an improvement of muscle strength but not in any difference between the four different methods of training. Thirty maximum contractions were required at each of the sixteen training sessions.

Mathews and Kruse (30) studied sixty subjects exercising isometrically using Clarke's Cable-Tension Strength Tests, and sixty



isotonically on a Kelso-Hellebrandt ergometer. Each group was divided into four and exercised two, three, four and five times weekly. It was found that the subjects reacted to exercise frequency individually but as exercise frequency increased more subjects increased in strength in both isotonic and isometric groups.

Rasch and Morehouse (36) compared two groups of subjects: one group performing isotonic progressive resistance exercise of presses and curls, and a second performing isometric exercises on a strain gauge dynamometer. The study lasted for six weeks during which time the subjects exercise for approximately one and one-half minutes per day, three times a week. In elbow flexion exercise the mean strength for the isotonic group increased significantly but no appreciable change occurred in the isometric group's mean strength. For exercises elevating the arm both the isotonic and the isometric group showed significant mean increases in strength but the isotonic group's increase was greater.

Using the abductor digiti quinti muscle because of its comparative lack of use, Asa (5) studied the effect of isotonic and isometric exercises on the strength and endurance of the muscle. Two isometric groups, one performing twenty contractions per day for six seconds four times per week for twelve weeks, and the second performing one contraction a day over the same days. Asa reported that subjects in both groups significantly increased in strength and the repetitive contraction group gained strength to a higher degree. The isotonic group exercised by using the DeLorme method and, although there was a significant increase in strength for all subjects, when compared with the repetitive isometric group the increase was significantly less. There



was no significant difference between these two groups with respect to endurance.

In a battery of tests, Meadows (31) reported no significant differences between isometric and isotonic groups in leg lift, back lift, vertical jump, dips, force of offensive charge and speed of offensive charge. The two groups trained for the same length of time (ten weeks, three days a week). The isotonic group improved significantly in chins compared to the isometric group.

Walters, et.al. (45) investigated the effects of isotonic exercise with two-thirds maximal resistance, isometric exercise at two-thirds maximal resistance, and isometric exercise at maximal resistance. Although both isometric methods increased strength significantly, the maximal isometric method was more effective than isometric at two-thirds maximum.

Petersen (35) compared the effect of training by eccentric, concentric, and isometric contractions on the flexor muscles of the arm and the extensors of the knee. The experimental design comprised four groups of young males and females: group I performed one maximum isometric contraction per day; group II ten maximum isometric contractions per day; group III performed ten eccentric contractions for the elbow flexors and rode fifteen minutes on the bicycle ergometer for the knee extensors; group IV was a control. Ten daily isometric contractions tended to increase the isometric strength of the muscles but not significantly, but the ten eccentric contractions did not. However, training on the bicycle ergometer increased the isometric strength of the extensors.

Lawrence, et.al. (28) compared the effect of isotonic training



with that of isometric training on the strength increase in the quadriceps femoris muscle. Results indicated that the strength increase was greater from isotonic than from isometric exercise but endurance increase was greater from isometric than isotonic exercise.

Richardson (37) tested sixty grade ten boys divided into three groups: a group which trained isotonically-isometrically whereby subjects lifted a weight and then held it; a group which trained isometrically at a knee angle of 115 degrees, and a third group which trained isometrically at 135 degrees. Results showed that the isotonic group had an increase which was significantly greater than the 135 degree angle isometric group but there was no significance between the isotonic and the 115 degree angle isometric group.

Calculation of Oxygen Cost of Activity. The structure and chemistry of muscle is such that in muscular contractions oxygen is required only in the recovery process and not in the primary breakdown. Hill (21:42) states that "a muscle behaves like an accumulator which can be discharged without any kind of combustion or any kind of provision of energy from without: it requires external energy only when it has to be recharged."

Karpovich (26) makes the distinction between "resting metabolism", which represents the amount of energy expended during inactivity, and "basal metabolism" which is applied to the lowest energy necessary for mere existence. Basal metabolism varies with age, height, weight and sex but Karpovich states that "in the average athlete it may be equivalent to 200 - 255 c.c. of oxygen per minute, or roughly, about one large calorie per hour per kilogram of body weight." (26:423). Karpovich



clearly explains the principles of metabolism testing and the procedure for the method of indirect calorimetry using the Douglas bag and analysis of expired air.

White, et.al. (46) state that age and sex affect the basal metabolism with values being higher in childhood than in adult life, and higher in males than females of the same age. The most important factor influencing basal metabolism is body size in terms of surface area. Among other factors which may affect basal metabolism are environmental temperature, with temperatures above 30°C causing a slight rise in the metabolic rate; muscular training, with the trained athlete having a slightly higher basal metabolic rate.

Consolazio, et.al. (8) distinguish between the open-circuit and closed-circuit method of indirect calorimetry, or respiratory calorimetry. The open-circuit method allows the subject to breathe air from the outside and expire air into a Douglas bag for volumetric measurement. This gas volume is corrected for standard conditions and may be analyzed for oxygen and carbon dioxide content, with the subsequent calculations of oxygen consumption and carbon dioxide production. Consolazio, et.al. outline the procedures and calculations to reduce expired air collection to an estimation of energy expenditure or oxygen cost of activity.



## CHAPTER III

### METHODS AND PROCEDURE

Subjects. Thirty-three male freshmen enrolled at The University of Alberta in Physical Education 218 were selected as subjects on a random basis. Students enrolled in the Faculties of Physical Education and Engineering were not included in the experiment. The subjects were further designated on a random basis to one of three groups - eccentric (E), concentric (C) or isometric (I).

Experimental Design. The study lasted for ten weeks and comprised one week preliminary testing, nine training sessions, a mid-test, and another nine training sessions followed by the final test. The collection of anthropometrical data and the orientation period was carried out prior to the preliminary testing. Subjects were tested as near as possible to the same time for each testing session.

It was proposed, in theory, that subjects would train three days per week with as many as could be arranged training on alternate days. In practice, this did not occur and it can only be stated that no subject trained more than four times per week nor less than once per week.

Anthropometrical Data. The following anthropometrical data were collected from each subject: age (years and months); height (inches); weight (pounds); leg-length - measured in inches from the greater trochanter to the lateral epicondyle of the right leg, and from the lateral epicondyle to the lateral malleolus.



Orientation Period. Each subject brought to the laboratory was informed of the test involved and either participated in or observed a demonstration of the testing and training procedure.

Test Procedure for the Determination of Oxygen Cost. Each subject was tested to determine the oxygen cost of muscular contraction. A subject was tested as a member of the group to which he had been assigned - eccentric, concentric or isometric.

1. Eccentric Contraction Group (E).

(i) After the knee angle for the required contraction was checked, each subject rested for ten minutes. The rest position was with the subject seated on a stool placed on the leg dynamometer apparatus. The subject had the bar and belt with shoulder harness, and the restraining belt around the chest fitted, and the load cell was attached to the bar. The headgear to support the valve and mouthpiece necessary for the collection of expired air were in position with the nose-clip fitted but without the rubber-hose connection to the Douglas bags.

(ii) At the end of ten minutes the hose to the Douglas bag was fitted and expired air was collected for a period of two minutes. The resting metabolism for the purposes of this study was determined from the analysis of this expired air.

(iii) During a period of thirty seconds, the subject was prepared for the first contraction. No expired air was collected during this period.

(iv) The subject performed six eccentric muscular contractions by moving from a knee angle of 150 to 60 degrees of flexion at a constant



speed which was uniform for all subjects.<sup>1</sup> Between each contraction there was a period of fifteen seconds during which time the subject sat on the stool. Expired air for this period was collected in a second Douglas bag.

(v) Upon completion of the sixth contraction the subject rested for five minutes in the original rest position as described (section (i)) except that he expired into the third Douglas bag and this was taken as the recovery period.

## 2. Concentric Contraction Group (C).

(i) - (iii) As for (E) group.

(iv) Each subject performed six concentric contractions by moving from a knee angle of 60 to 150 degrees of flexion at a constant speed which was uniform for all subjects. The remaining part of this procedure was as for section (iv) of the (E) group.

## 3. Isometric Contraction Group (I).

(i) - (iii) As for (E) group.

(iv) Each subject performed six six-second isometric contractions at the knee angle of 100 degrees of flexion during which time the cable did not move.<sup>2</sup> The remaining part of this procedure was as for section

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<sup>1</sup> It was originally intended that each contraction would be of six seconds duration but it was found that most subjects required more time in which to move through the knee angle range. In this study, knee angle was regarded as a more important criteria than was a fixed amount of time for all subjects. See discussion on page 52.

<sup>2</sup> It was intended that each contraction for the subjects in the (I) group would be for a duration of six seconds. Results (Appendix B) showed that the contractions for this group, as for the others, were longer than six seconds. See discussion on page 54.



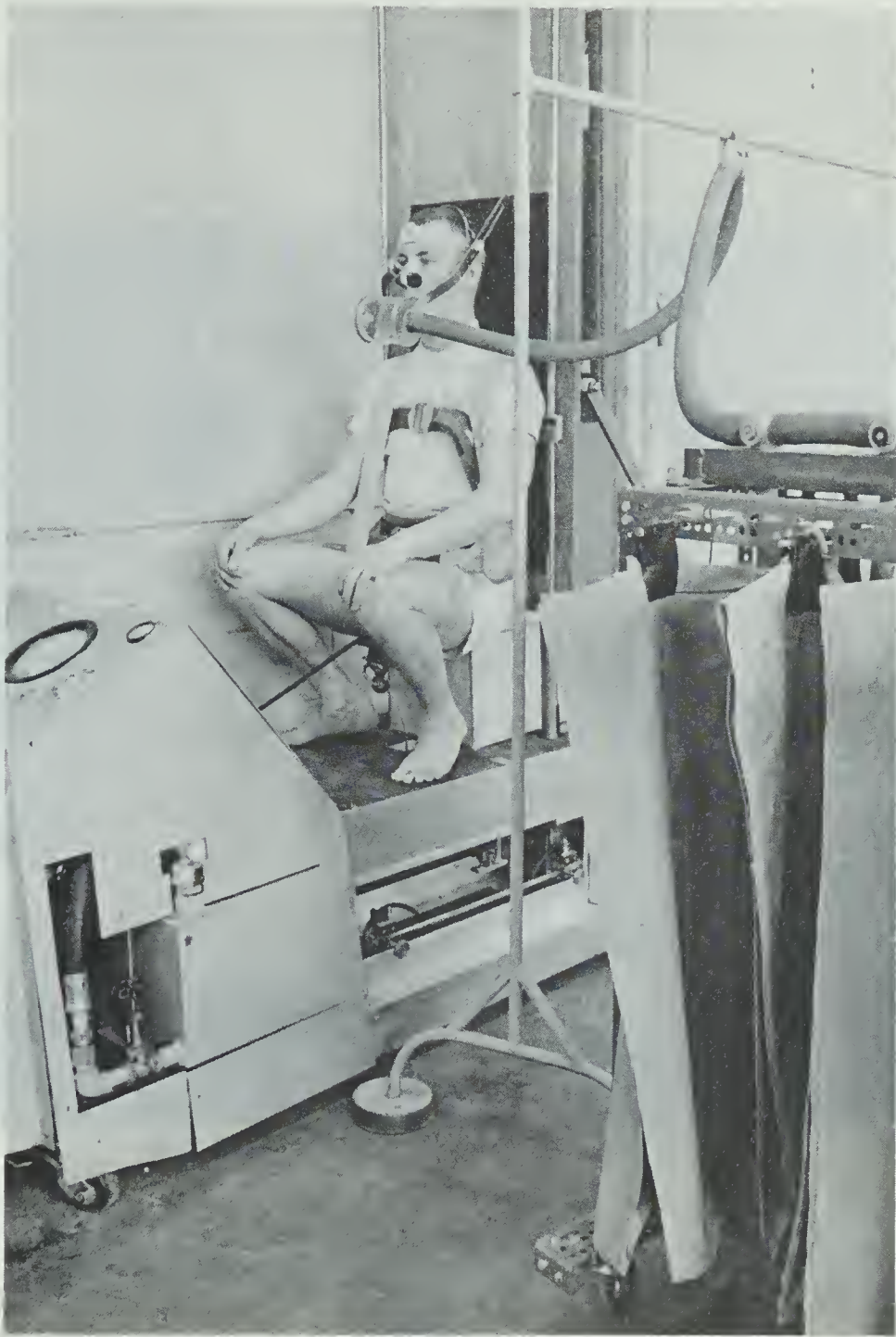


FIGURE 1

SUBJECT SEATED IN REST POSITION  
WITH APPARATUS FOR COLLECTION OF EXPIRED AIR



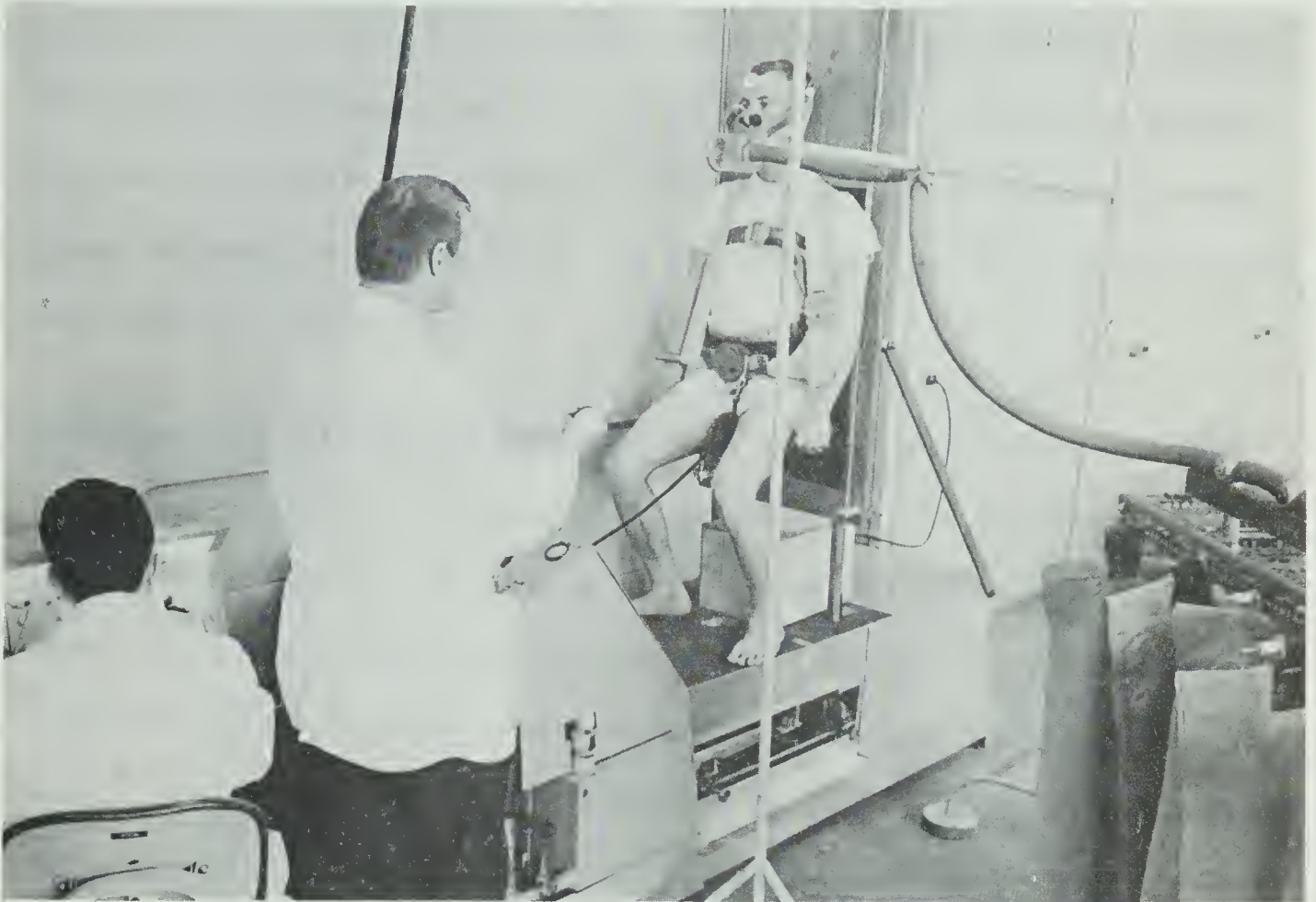


FIGURE 2

SUBJECT PERFORMING A CONTRACTION DURING WHICH  
EXPIRED AIR IS COLLECTED AND THE FORCE EXERTED  
IS RECORDED



(iv) of the (E) group.

(v) As for the (E) group.

Subsequent Testing for the Determination of Oxygen Cost. The testing procedure for the (E), (C) and (I) groups was repeated midway through the training programme and upon completion of the training programme. The data thus obtained determined the oxygen cost of three different types of muscular contractions and the effect of a particular training programme on oxygen cost.

Procedure for Training Programme. Each subject trained as a member of the particular contraction group to which he was assigned, and all contractions for the (C) and (E) groups were performed at a constant speed which was uniform for all subjects. The (I) group performed contractions of six seconds duration during which time the cable did not move.<sup>3</sup> The subject was fitted into the testing apparatus as described above except that no apparatus for the collection of expired air was connected, nor was the shoulder harness attached.

1. (E) Group. The subjects commenced at six eccentric contractions in the first week of training and increased this number by three after every third training session until a total of 18 contractions was reached. The subjects performed 18 contractions for the remaining period of the

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<sup>3</sup> Since it was found that contractions were longer than six seconds for the (I) group in the test, it was probable that contractions performed during training sessions were also longer. Since the dynamograph was not used to record the contraction force or time during training no data are available to verify this probability. See discussion on page 53.





FIGURE 3

SUBJECT PERFORMING DURING TRAINING  
WITH NO EQUIPMENT FOR EXPIRED  
AIR COLLECTION OR FOR RECORDING  
THE FORCE EXERTED



experiment.

2. (C) Group. As for (E) group except that the contractions during training were concentric.

3. (I) Group. As for (E) group except that the contractions during training were isometric and were performed at a knee angle of 100 degrees.

#### Experimental Apparatus - Strength Testing and Training.

Leg Dynamometer. The apparatus used for the testing and training of the subjects consisted of a two-horse power electric three phase motor connected by means of a flexible coupling to a Vickers eighteen gallon per minute vane pump, to a positive filter, to a directional control valve which enabled a double-acting hydraulic cylinder to go forward, backward or stop. The hydraulic cylinder had a three-inch diameter and a thirty-inch stroke. Connected to the cylinder was a cylinder rod and connected to this was a three thousand pound capacity cable. The cable passed over two ball-bearing pulleys so as to pass out and up from the machine at a point directly between the subject's feet. The cable was connected to the subject by means of a belt and bar with a shoulder harness.

The machine incorporated a start-stop mechanism for the operator together with micro-switches which automatically stopped the machine when it had gone too far in either an upward or downward direction.

Directly behind where the subject stood was attached a solid plywood back-support extending from one foot above the platform of the machine to seven feet. The surface of this back board was waxed to help



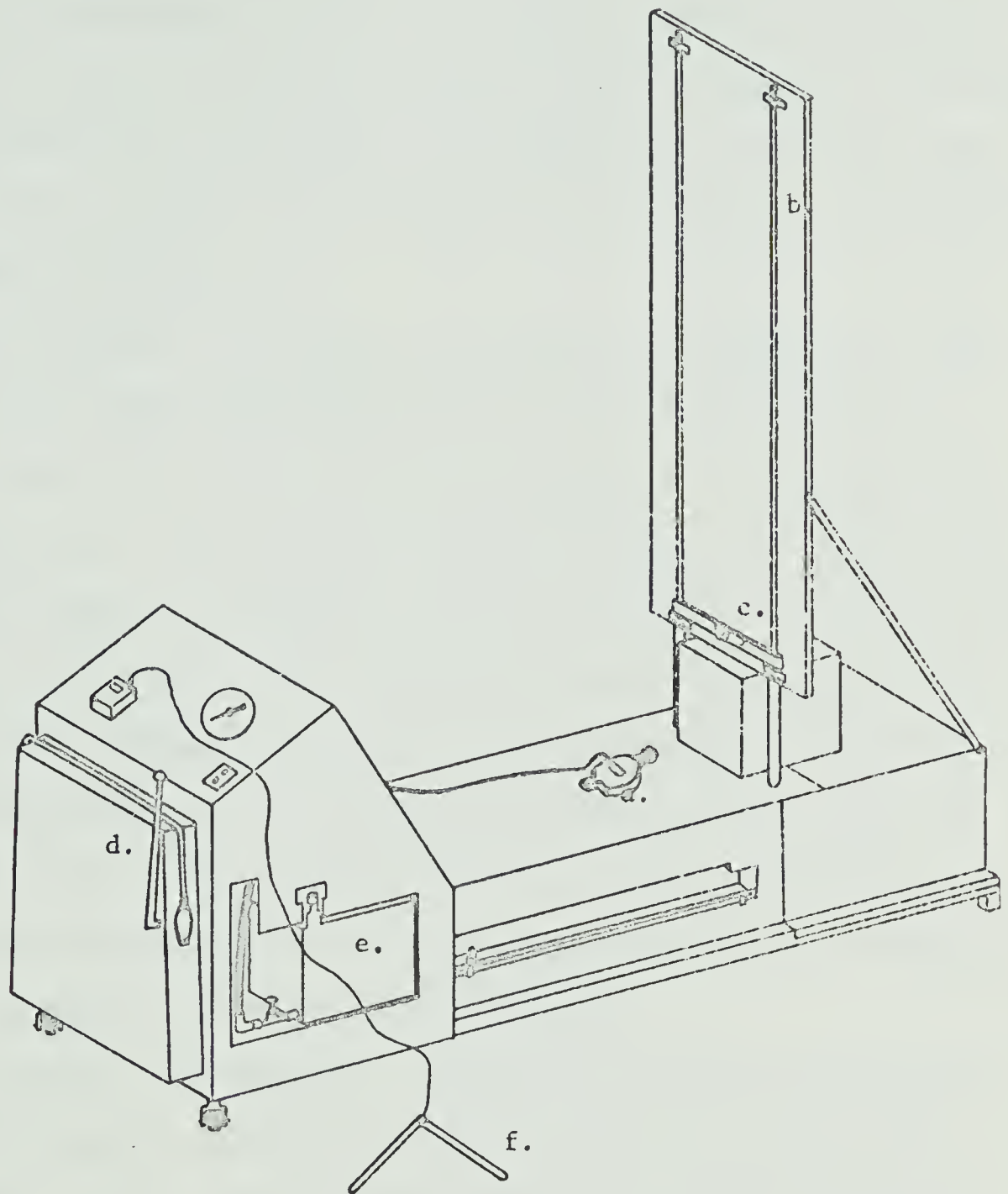


FIGURE 4

## EXPERIMENTAL LEG DYNAMOMETER

- a. Load Cell and Cable    b. Vertical Board    c. Restraining Belt  
d. Cable Length Adjustment Switch    e. Vane Pump  
f. Electrogoniometer



eliminate friction. On each side of the board were mounted steel rods on which ball-bearings travelled. Connected to each ball-bearing was half a car seat-belt so that the subject could be strapped to the board but could still move up and down. The subject was instructed to keep his buttocks, shoulders and head against this back board to standardize the problem of balance.

Bar and Belt. An especially designed belt consisted of a bar with a safety cable-release mechanism which could be pulled by the subject had he felt pain or unbearable discomfort at any time during the contraction. The bar itself was firmly attached to a four-inched webbed belt which was fastened on the subject by means of an automobile seat-belt buckle with a safety release mechanism. To ensure that the bar and belt slippage was minimized a shoulder harness was used which assisted in holding the bar so that the level of the hook on the bar was at the level of the subject's pubic bone. The possible effect of the shoulder movement on the bar during the contraction was minimized by having the subject lean against the back board.

Load Cell and Dynograph. Attached to the cable and bar was a 3,000 pound capacity load cell, model U 31 tension type from BLH Electronics. Power to and from the load cell was provided through a Beckman Type RS Dynograph with two-channels for recording. Signals from the load cell were received by and recorded on the dynograph which was calibrated to move one millimetre for every 100 pounds tension on the load cell.

Sargent Recorder (Model SR). The signals received on the dynograph were simultaneously amplified on a Sargent recorder. This machine



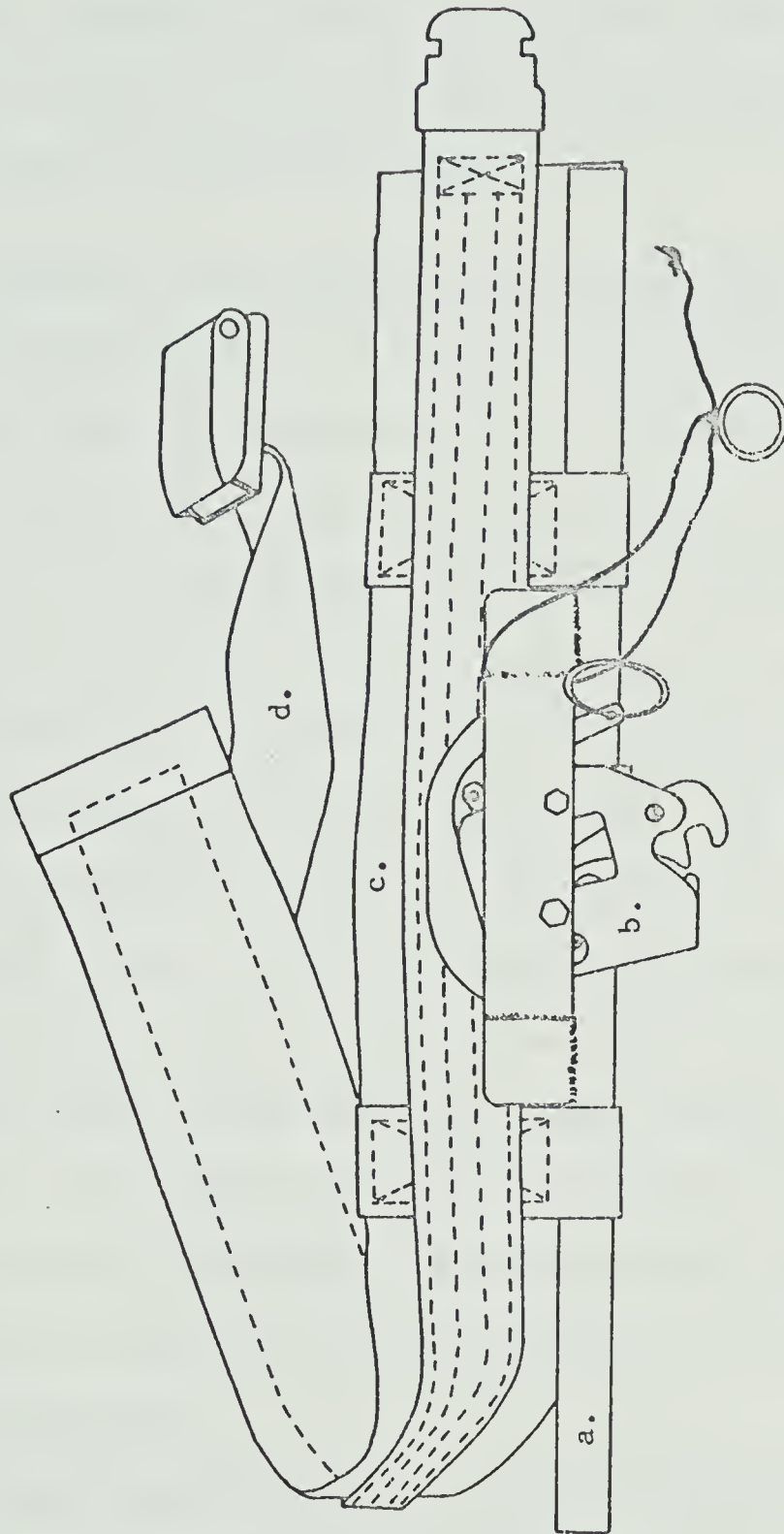


FIGURE 5

## EXPERIMENTAL BAR AND BELT

- a. Bar    b. Safety Release Mechanism    c. Four-inch Webbed Belt  
d. Automobile Seat Belt.



was calibrated to 3,000 pounds and the pounds pull was read as per cent of 3,000 pounds. Accuracy to within three pounds could be achieved by interpolating to tenths of divisions and without interpolation the machine was accurate to within 30 pounds.

#### Experimental Apparatus - Gas Analysis to determine Oxygen Cost.

Valve and Douglas Bags. A two-way valve which enabled the subject to inhale room air and expire into the Douglas bags was used and to prevent respiration through the nasal passages a nose clip was applied. Hoses of 1.5 inch diameter connected the valve to the Douglas bags which were of 150 litre size and hung loosely on a portable trolley.

Oxygen Analyser. A Beckman model E-2 oxygen analyser was used to determine the partial pressure of a gas sample. The analysis system of the instrument measured the magnetic susceptibility of the gas with a magnetic torsion balance. A 60 cycle Neptune Dyna-pump, Model 2, was used to pump a gas sample through the analyser, and after this sample value was read a second sample was pumped through the analyser for 15 seconds. If no change was noted, the value was recorded. When adjustment was necessary additional 15 second readings were analysed and for each 15 second reading 75 c.c. air was added to the total volume of the Douglas bag sample.

Godard Capnograph CO<sub>2</sub> Analyser. Carbon dioxide analysis was carried out by using the Godart Capnograph Analyser in which the principle of measuring is the absorption of infra-red rays by carbon dioxide gas. This apparatus was constructed to transmit infra-red light of a specified wave length, one which carbon dioxide will absorb. The beam emitted



is passed through the mixture of gases which contains an unknown percentage of carbon dioxide. The concentration of carbon dioxide can be measured from the reduction in intensity of the rays. A 15 second expired air sample was pumped into the analyser by a pump within the capnograph.

American Volume Meter (Model 802). The volume of expired air was measured by an American Volume Meter in liters. A hose of 1.5 inch diameter was attached to the Douglas bag apparatus and the bag was emptied by using a Dayton 5,000 r.p.m. pump, Model 2M138.

Calculation of Oxygen Cost. The oxygen consumption and carbon dioxide production was calculated from the volume of expired air, and the carbon dioxide, oxygen and nitrogen content of the expired air as compared with the inspired air. From this data oxygen cost was subsequently computed as outlined by Consolazio, et.al. (8:5).

Calibration of the Apparatus. The load cell, dynograph and enlarger were calibrated by comparing the indicated deflection on the graph with a known load on a strain-gauge calibrator accurate to two pounds. For the Sargent enlarger a 3,000 pound pull was set to 100 per cent and lesser pulls were read as per cent of 3,000 pounds.

The calibration gases used for calibrating the Beckman Oxygen Analyser and Godart Capnograph were evaluated by means of the analytical procedure outlined by Scholander (40).

The calibration of the American Volume Meter was carried out on a Collins Wet-Spirometer for measurement accuracy. From a regression analysis of collected data a corrected Atmosphere Temperature Pressure



Saturated (ATPS) was obtained.

Statistical Treatment. The significances of the differences between the means on the tests were tested with an analysis of variance technique for a two factor experiment with repeated measures on one factor (47:302).



## CHAPTER IV

### RESULTS AND DISCUSSION

#### Results

The analysis of the data is presented in the following manner. The means, standard deviations and ranges of age, height, weight and leg-length of all the subjects are presented in tabular form. Summaries of the two way analyses of variance with repeated measures on one factor for Oxygen Consumption per pound-second, Average Force in pounds per second, and Oxygen Consumption in millilitres per second precede written elaboration of results. Where significant differences occurred in Oxygen Consumption per pound-second, and Average Force in pounds per second, Newman-Keuls tests on row means were conducted and the results of these are presented. Finally, graphic representations of Oxygen Consumption per pound-second, Average Force in pounds per second, and Oxygen Consumption in millilitres per second for concentric, eccentric and isometric contraction groups over the pre-, mid-, and post-test periods are presented.

The means, standard deviations, and ranges of age, height, weight, and leg-length for the concentric, eccentric and isometric contraction groups are depicted in Tables I, II, and III respectively. The tables indicated that there were no significant differences between contraction groups in age, height, weight, and leg-length.



TABLE I

MEAN, STANDARD DEVIATION, AND RANGE OF AGE  
HEIGHT, WEIGHT, AND LEG LENGTH OF  
SUBJECTS IN CONCENTRIC CONTRACTION GROUP

Parameter	Mean	Standard Deviation	Range
Age (yrs.)	19.2	1.6	17.7 - 23.2 (5.5)
Height (ins.)	69.3	2.0	66.0 - 72.5 (6.5)
Weight (lbs.)	149.1	16.8	123.0 - 174.5 (51.5)
Upper Leg (ins.)	15.8	1.1	14.0 - 17.5 (3.5)
Lower Leg (ins.)	16.7	0.8	15.5 - 18.0 (2.5)

TABLE II

MEAN, STANDARD DEVIATION AND RANGE OF AGE,  
HEIGHT, WEIGHT, AND LEG LENGTH OF  
SUBJECTS IN ECCENTRIC CONTRACTION GROUP

Parameter	Mean	Standard Deviation	Range
Age (yrs.)	19.2	1.7	17.9 - 24.5 (6.6)
Height (ins.)	69.6	2.0	65.25 - 72.0 (6.75)
Weight (lbs.)	153.0	13.7	127.0 - 178.0 (51.0)
Upper Leg (ins.)	16.2	0.8	14.5 - 17.75 (3.25)
Lower Leg (ins.)	16.9	0.9	15.0 - 18.25 (3.25)



TABLE III  
MEAN, STANDARD DEVIATION, AND RANGE OF AGE,  
HEIGHT, WEIGHT, AND LEG LENGTH OF  
SUBJECTS IN ISOMETRIC CONTRACTION GROUP

Parameter	Mean	Standard Deviation	Range
Age (yrs.)	19.0	.9	17.2 - 20.4 (3.2)
Height (ins.)	68.3	2.2	65.0 - 72.75 (7.75)
Weight (lbs.)	144.6	19.0	115.0 - 192.0 (77.0)
Upper Leg (ins.)	15.6	1.0	14.0 - 17.5 (3.5)
Lower Leg (ins.)	16.3	0.8	15.0 - 17.5 (2.5)

Tables IV and V depict the Contraction Group by Test cell means, and the Summary of the Two-way Analysis of Variance with repeated measures on one factor (46:302-308) for the Oxygen Consumption per pound-second, respectively.

TABLE IV  
CONTRACTION GROUP BY TEST CELL MEANS FOR  
OXYGEN CONSUMPTION PER POUND-SECOND

Contraction Groups	Tests			Row Total	Row Mean
	Pre-Test	Mid-Test	Post Test		
Concentric	.497	.499	.432	1.428	.476
Eccentric	.210	.178	.166	.554	.186
Isometric	.255	.216	.295	.766	.255



TABLE V

TWO WAY ANALYSIS OF VARIANCE WITH REPEATED  
MEASURES ON ONE FACTOR - SUMMARY  
OXYGEN CONSUMPTION PER POUND-SECOND

Source of Variation	Sums of Squares	df	Mean Squares	F	P
Between Subjects	1.806	32			
'A' Main Effects (Contraction Groups)	1.514	2	0.757	67.806	0.0000000
Subjects within groups	0.335	30	0.011		
Within Subjects	0.503	66			
'B' Main Effects (Training Time)	0.012	2	0.006	0.814	0.4480765
'A'*'B' Interaction	0.066	4	0.016	2.313	0.0677853
'B' x Subjects within groups	0.427	60	0.007		
F.05 df 2,30 3.32, F.05 df 2,60 3.15, F.05 df 4,60 2.52					

Analysis of variance using scores reduced to the final form of Oxygen Consumption (millilitres/sec. per lb/sec.) yielded a significant F value for the Contraction Groups. The error term (subjects within groups) for Between Subjects was low when compared with the mean squares of the contraction groups. From such comparison, it seemed the reliability of this test was reasonably high unless the experimental error was not uniform for each of the three contraction groups. There was no reason to expect that the experimental error of the tests was greater for any one group than for any other. Neither the effect of training nor the training by contraction group interaction yielded significant F values, although the latter did approach significance.



TABLE VI  
NEWMAN-KEULS TESTS ON ROW MEANS  
OF OXYGEN CONSUMPTION - PER POUND-SECOND

Contraction Groups		Eccentric	Isometric	Concentric
Ordered Means		.186	.255	.476
Difference between pairs	Eccentric	-	.069 *	.290 *
	Isometric		-	.221 *
Truncated Range r			2	3
q 95 (r,30)			2.89	3.49
q 95 (r,30)	$\sqrt{\frac{MS \text{ subjects within groups}}{nq}}$		.049	.059

\* difference significant when greater than Truncated Range r for that order.

The Newman-Keuls test (46:309-311) on the differences between the row means, as shown in Table VI, revealed that the differences between all contraction groups were significant, with the greatest difference being between the eccentric and concentric contraction groups.

Figure 6 graphically depicts the relationships of the three contraction groups. The concentric group consumed significantly more oxygen per pound-second than the eccentric and isometric groups, the ratios of the row means being 2.6 and 1.9, respectively. There was also a significant difference between the isometric and eccentric contraction groups, and the ratio of these groups in respect to amount of oxygen consumed was 1.4.

Although none were significant, Figure 6 also shows the fluctuations of oxygen consumption per pound-second within the groups over the three tests. The concentric contraction group always remained highest but did consume less oxygen in the final test than in the pre-



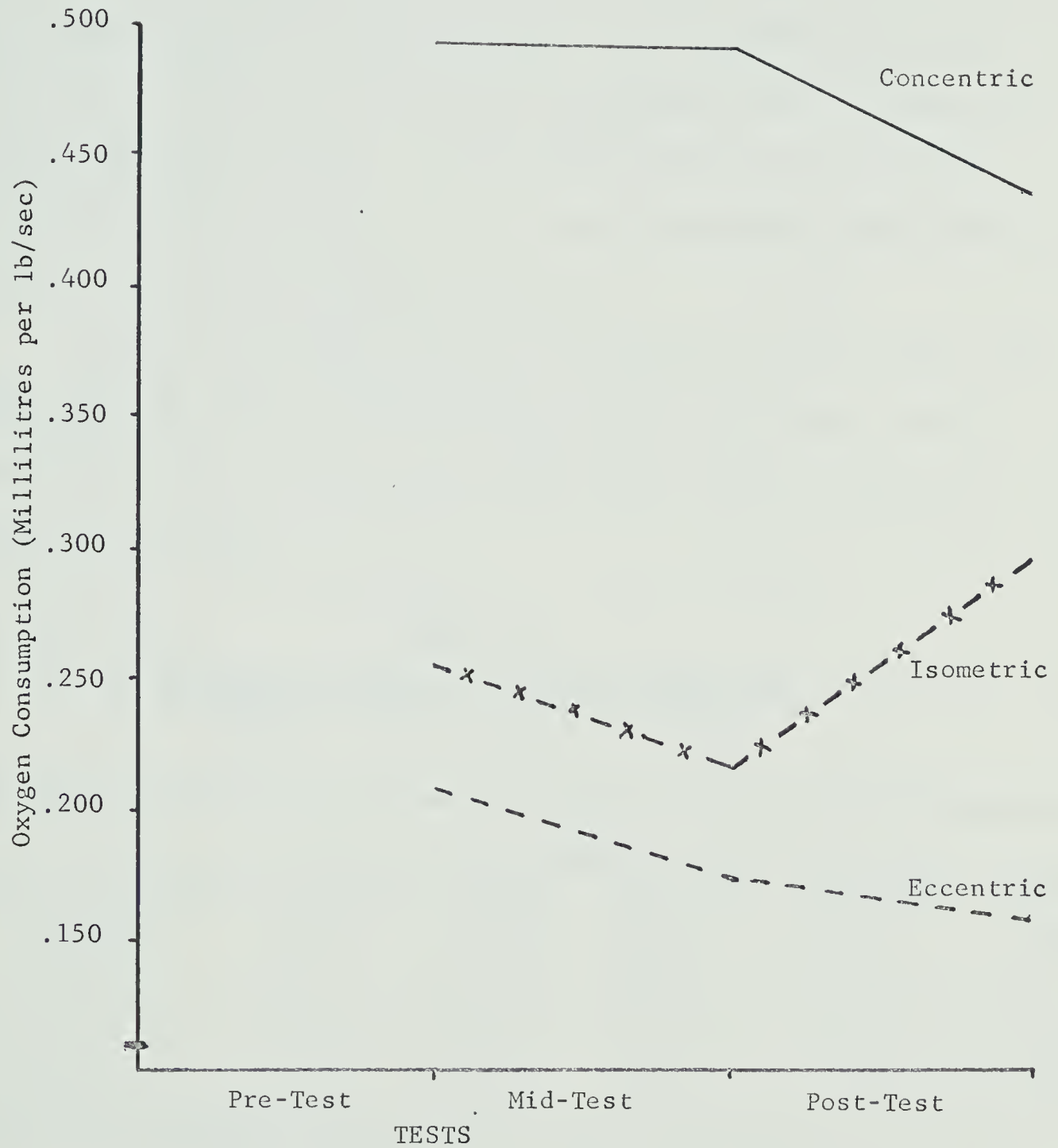


FIGURE 6

OXYGEN CONSUMPTION PER POUND-SECOND  
FOR CONCENTRIC, ECCENTRIC AND ISOMETRIC  
CONTRACTION GROUPS



and mid-tests. The isometric contraction was always higher than the eccentric contraction group but this difference increased in the post-test when the isometric group increased in oxygen consumption to a value higher than that of the pre-test. The eccentric contraction group was the only group to maintain a downward trend in oxygen consumption per pound-second. The post-test value for this group was one-third of the pre-test value, and less than one-half that of the post-test value for the concentric group.

Tables VII and VIII depict the Contraction Group by Test cell means, and the Summary of the Two-way Analysis of Variance with repeated measures on one factor for the Average Force in pounds per second, respectively.

TABLE VII

CONTRACTION GROUP BY TEST CELL MEANS FOR  
AVERAGE FORCE IN POUNDS PER SECOND

Contraction Groups	Tests			Row Totals	Row Means
	Pre-Test	Mid-Test	Post-Test		
Concentric	150.21	157.03	163.94	471.18	157.06
Eccentric	380.92	356.22	401.48	1138.62	379.53
Isometric	253.29	292.15	227.24	772.68	257.56



TABLE VIII

TWO WAY ANALYSIS OF VARIANCE WITH REPEATED  
MEASURES ON ONE FACTOR - SUMMARY  
AVERAGE FORCE IN POUNDS PER SECOND

Sources of Variation	Sums of Squares	df	Mean Squares	F	P
Between Subjects		32			
'A' Main Effects (Contraction Groups)	8.4703.812	2	407,351.875	52.383	0.0000000
Subjects within groups	233293.000	30	7,776.430		
Within Subjects	228241.000	66			
'B' Main Effects (Training Time)	810.870	2	405.435	0.127	0.8809278
'A'*'B' Interaction	34812.727	4	8703.180	2.727	0.0374139
'B' x Subjects within groups	191492.000	60	3191.533		
F.05 df 2,30 3.32, F.05 df 2,60 3.15, F.05 df 2,60 2.52					

The results of the two way analysis of variance with repeated measures on the Average Force in pounds per second are summarized in Table VIII. The analysis of variance yielded a highly significant F value among the Contraction Groups. The error term (subjects within groups) for Between Subjects was again comparatively low in relation to the mean squares of the Contraction Groups.

The effect of training within subjects was not significant but the Training by Contraction Group interaction did yield a significant F value. Figure 7 shows the pattern of this interaction as well as the relationship of the three contraction groups. The concentric contraction group remained the lowest in average force in pounds per second for all tests and it was



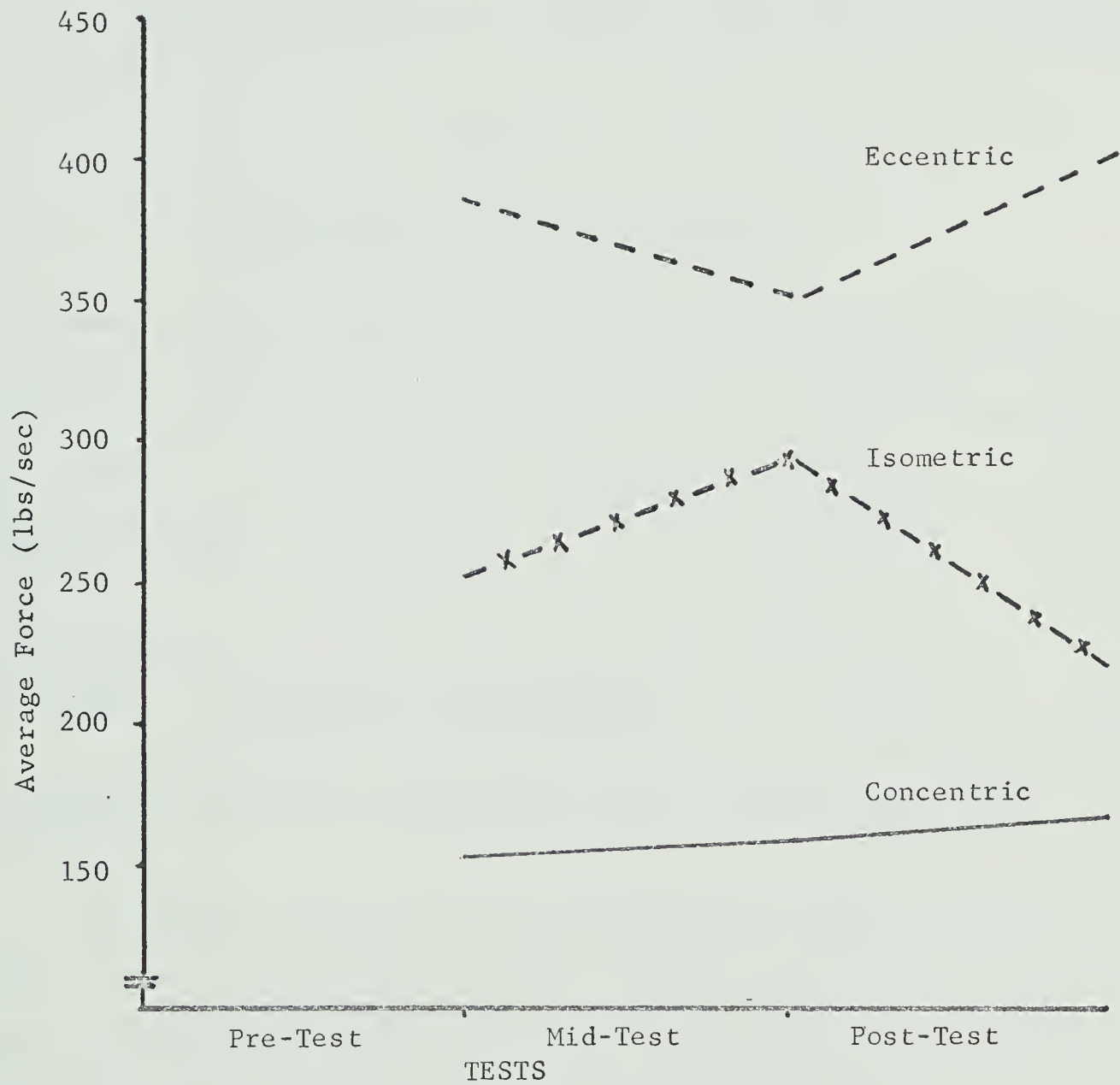


FIGURE 7

AVERAGE FORCE IN POUNDS PER SECOND  
FOR CONCENTRIC, ECCENTRIC, AND  
ISOMETRIC CONTRACTION GROUPS



the only group which remained relatively uniform, having only a slight increase over the three tests. Both the eccentric and isometric contraction groups showed fluctuations over the three tests with the former decreasing at the mid-test but increasing to higher than the pre-test for the post-test. The isometric group increased in average force pounds for the mid-test but decreased to lower than the pre-test level for the post-test.

TABLE IX  
NEWMAN-KEULS TESTS ON ROW MEANS  
OF AVERAGE FORCE - POUNDS PER SECOND

Contraction Groups		Concentric	Isometric	Eccentric
Ordered Means		157.06	257.56	379.53
Difference between pairs	Concentric	-	100.5 *	222.47 *
	Isometric		-	121.97 *
Truncated Range r			2	3
q 95 (r,30)			2.89	3.49
q 95 (r,30)		$\sqrt{\frac{MS \text{ subjects within groups}}{nq}}$		
			44.48	53.71

\* difference significant when greater than Truncated Range r for that order.

The Newman-Keuls test on the differences between row means as shown in Table IX indicates that the differences between all contraction groups were significant and, as for the Oxygen Consumption per pound-second, the greatest difference was between the eccentric and concentric contraction groups.

A comparison of Figure 6 and Figure 7 indicated that the concentric contraction group produced the least Average Force in pounds per second at the greatest cost in terms of Oxygen Consumption per pound-second.



Conversely, the graphs showed that the eccentric contraction group produced the most force at the least cost. The isometric group remained between these two groups on both Average Force and Oxygen Consumption per pound-second. All differences were significant at .05 level.

Tables X and XI depict the Contraction Group by Test cell means, and the Summary repeated measures on one factor for the Oxygen Consumption in millilitres per second, respectively.

TABLE X  
CONTRACTION GROUP BY TEST CELL MEANS FOR  
OXYGEN CONSUMPTION - MILLILITRES PER SECOND

Contraction Groups	Tests			Row Totals	Row Means
	Pre-Test	Mid-Test	Post-Test		
Concentric	72.14	75.72	68.66	216.52	72.17
Eccentric	77.45	64.30	64.48	206.23	68.74
Isometric	60.55	58.40	64.45	183.40	61.13



TABLE XI

TWO WAY ANALYSIS OF VARIANCE WITH REPEATED  
MEASURES ON ONE FACTOR - SUMMARY  
OXYGEN CONSUMPTION - MILLILITRES PER SECOND

Source of Variation	Sums of Squares	df	Mean Squares	F	P
Between Subjects	15107.375	32			
'A' Main Effects (Contraction Groups)	2095.845	2	1047.922	2.406	0.1073213
Subjects within groups	13064.250	30	435.475		
Within Subjects	16144.062	66			
'B' Main Effects (Training Time)	359.712	2	179.856	0.753	0.4751648
'A'*'B' Interaction	1362.190	4	340.547	1.426	0.2362218
'B' x Subjects within groups	14324.062	60	238.734		
$F_{.05 \text{ df } 2,30} = 3.32, F_{.05 \text{ df } 2,60} = 3.15, F_{.05 \text{ df } 4,60} = 2.52$					

The results of the two way analysis of variance with repeated measures on one factor for the Oxygen Consumption in millilitres per second are summarized in Table XI. The analysis of variance did not yield any significant F values although the Contraction Groups for Between Subjects did approach significance. Figure 8 shows the relationships of the three contraction groups but such relationships were not as distinct as for Average Force in pounds per second (Figure 7) or Oxygen Consumption per pound-second (Figure 6). Figure 6 shows that the eccentric group always consumed less oxygen than concentric although this consumption increased for the post-test for eccentric and decreased for concentric. The values of the



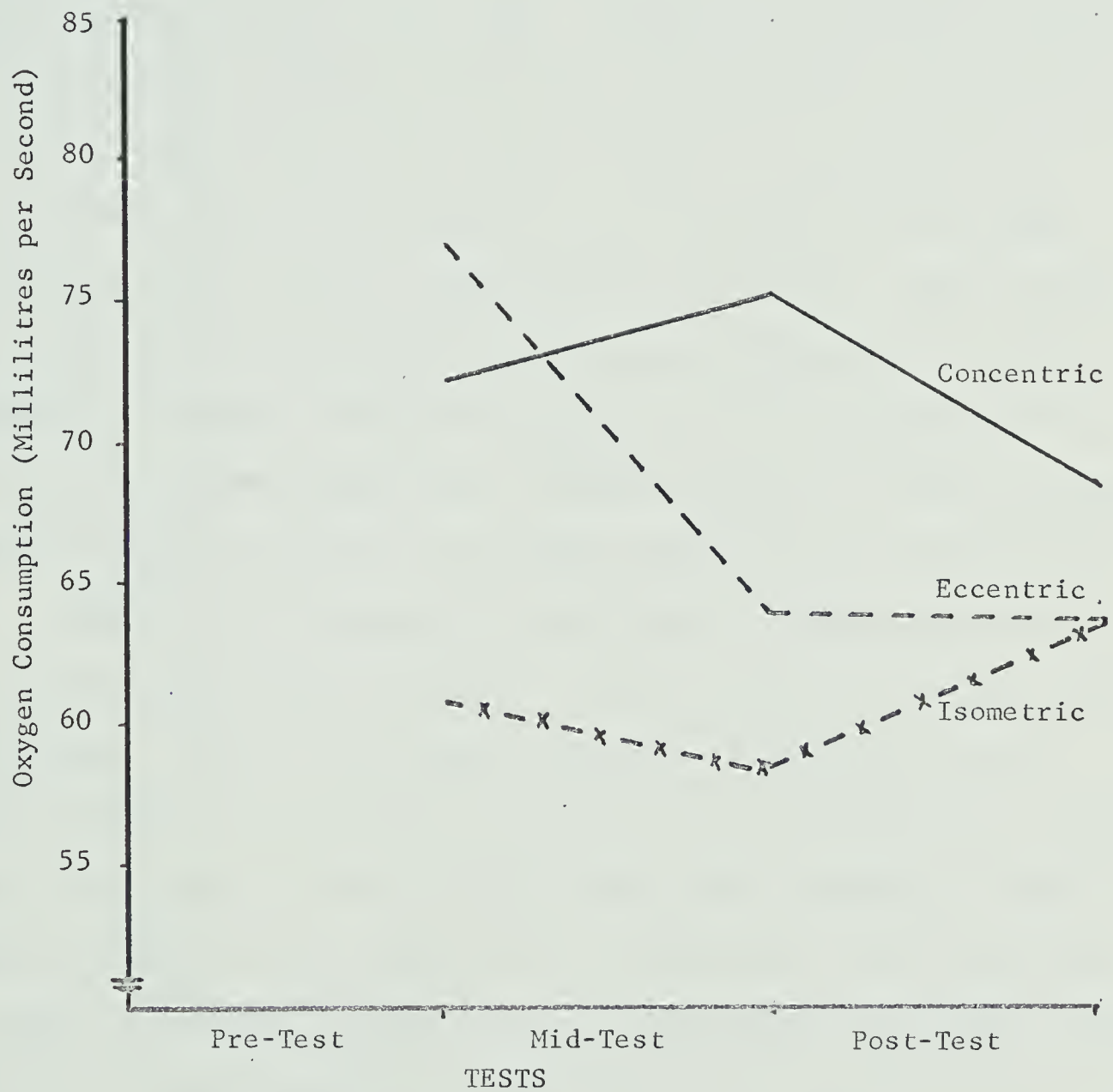


FIGURE 8

OXYGEN CONSUMPTION IN MILLILITRES  
PER SECOND FOR CONCENTRIC, ECCENTRIC,  
AND ISOMETRIC CONTRACTION GROUPS



isometric group fluctuated most; from highest on the pre-test to lowest on the post-test.

Figures 9, 10 and 11 graphically depict the scores for Oxygen Consumption per pound-second, Oxygen Consumption in millilitres per second, and the Average Force in pounds per second for the three contraction groups over the three tests. Although the analyses of variance did not yield any significant differences over the three test periods, the following observations were worth noting. The concentric contraction group (Figure 9) increased in both Average Force and Oxygen Consumption in the mid-test compared with the pre-test. This resulted in a slight increase in Oxygen Consumption per pound-second. In the post-test, the Oxygen Consumption decreased to a level lower than for the pre-test and the Average Force increased slightly. These two factors combined caused a decrease in the Oxygen Consumption per pound-second.

The eccentric contraction group (Figure 10) decreased in both Average Force and Oxygen Consumption in the mid-test when compared with the pre-test. However, the Oxygen Consumption decreased to such an extent that the overall effect was a lower Oxygen Consumption per pound-second. The results of the post-test indicated an increase of fifty-pounds Average Force per second, but the maintenance of the same value for Oxygen Consumption in this test as for the mid-test realized a further decrease in Oxygen Consumption per pound-second. The eccentric contraction group was the only group which consistently reduced the amount of Oxygen Consumption per pound-second over the three tests.

The isometric contraction group (Figure 11) increased in Average Force and decreased the Oxygen Consumption in the mid-test as compared



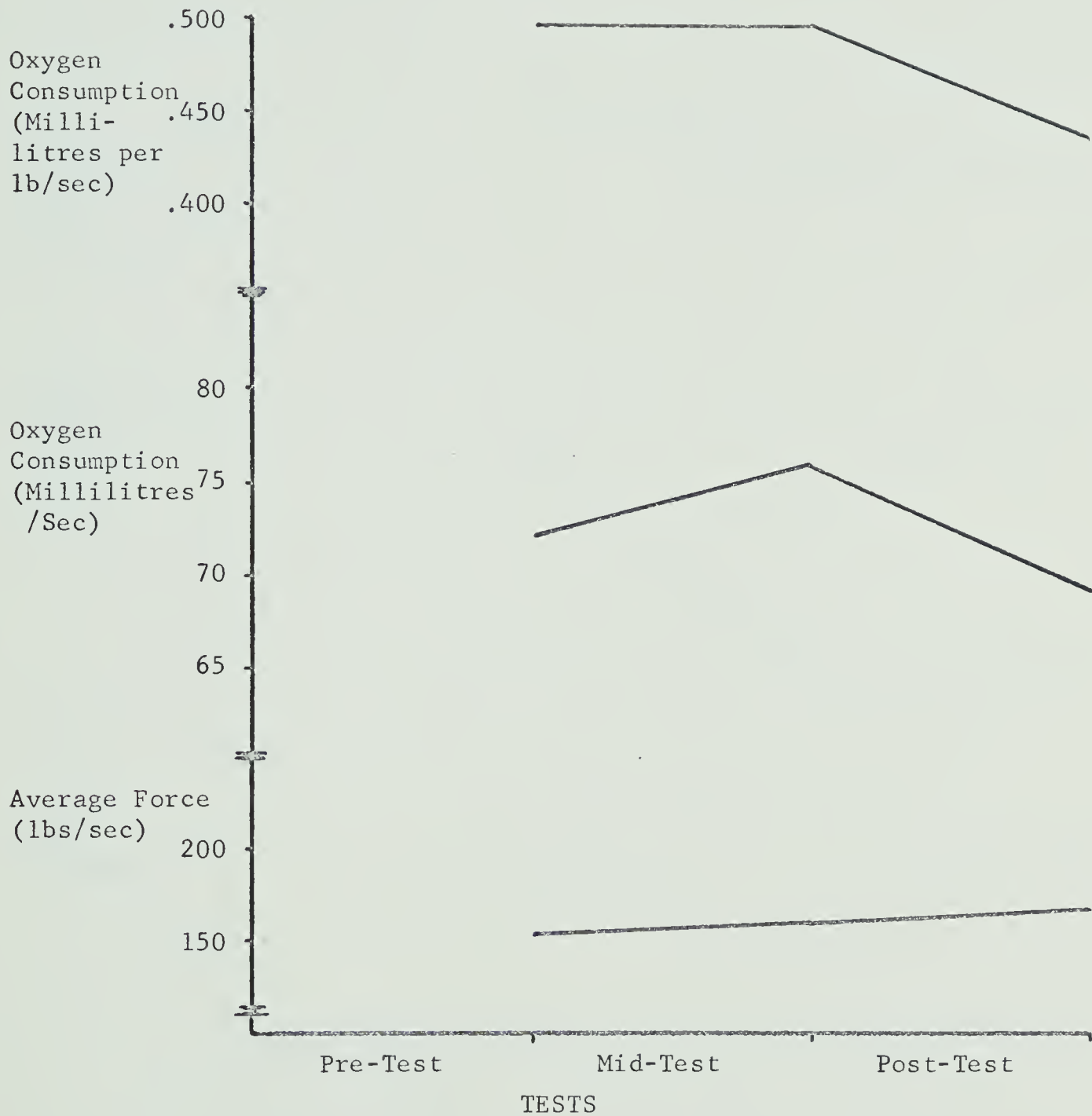


FIGURE 9

OXYGEN CONSUMPTION PER POUND-SECOND, OXYGEN  
CONSUMPTION IN MILLILITRES PER SECOND, AND  
AVERAGE FORCE IN POUNDS PER SECOND FOR  
CONCENTRIC CONTRACTION GROUP



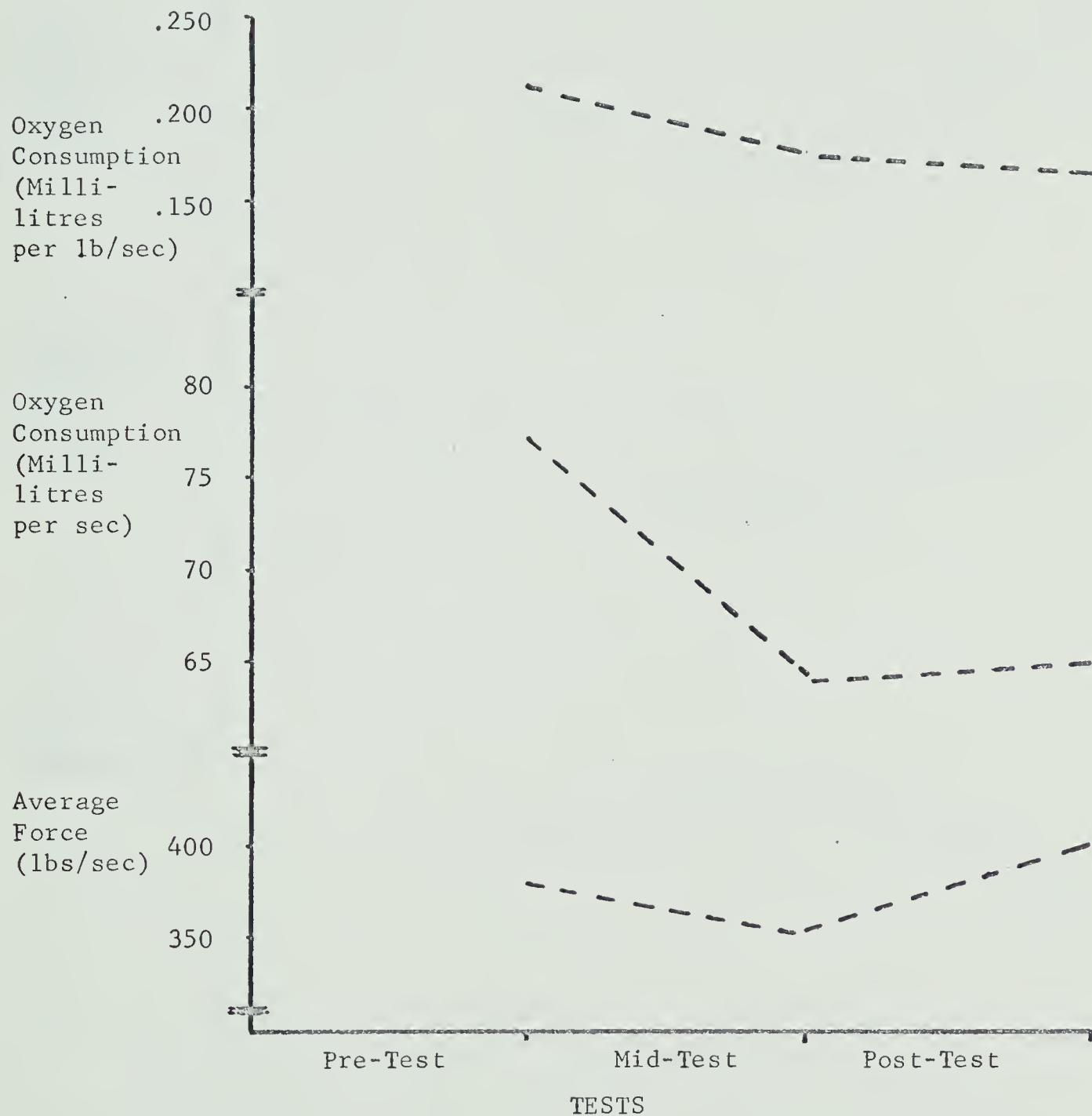


FIGURE 10

OXYGEN CONSUMPTION PER POUND-SECOND,  
OXYGEN CONSUMPTION IN MILLILITRES PER SECOND,  
AND AVERAGE FORCE IN POUNDS PER SECOND  
FOR ECCENTRIC CONTRACTION GROUP



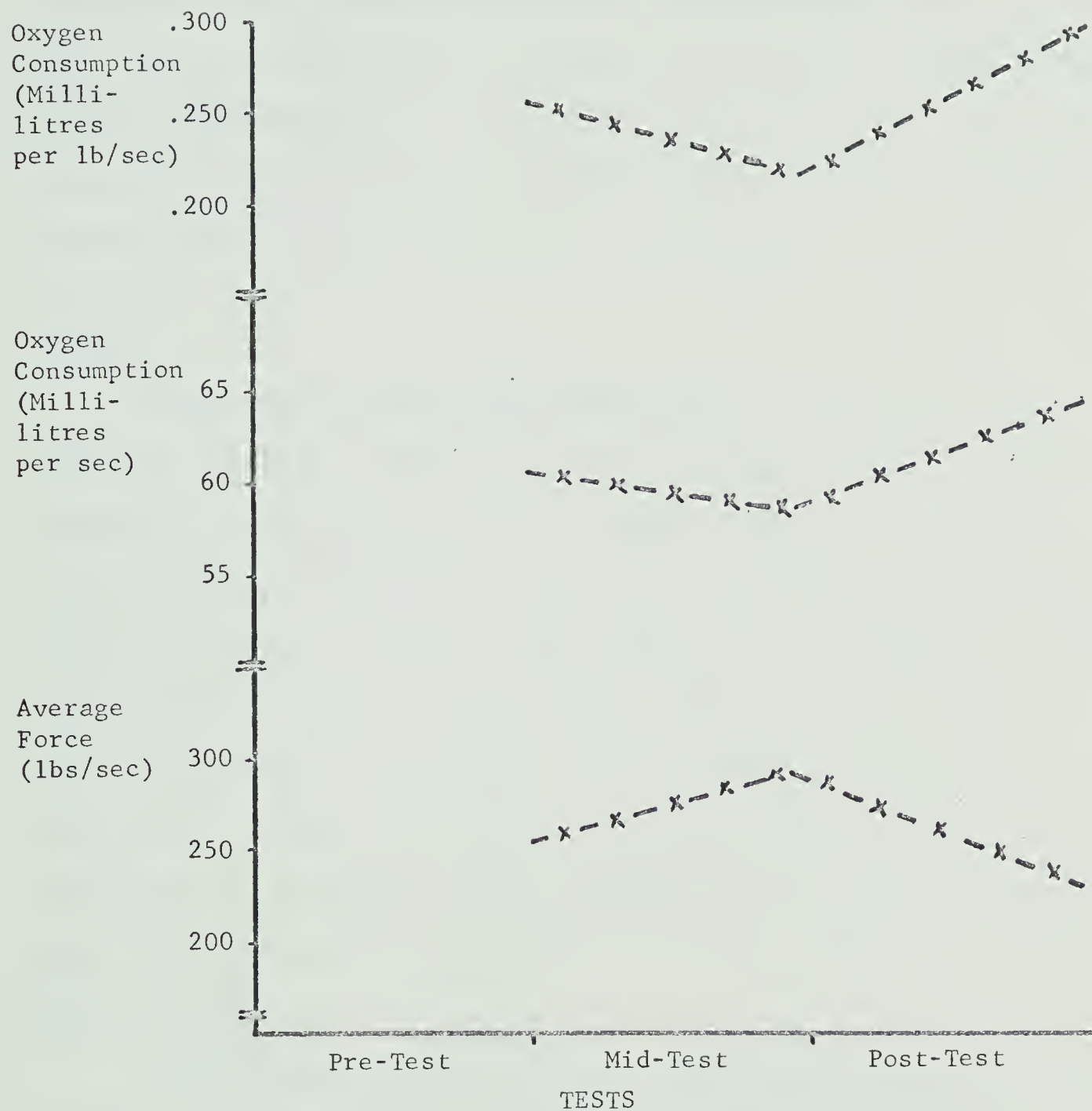


FIGURE 11

OXYGEN CONSUMPTION PER POUND-SECOND, OXYGEN  
 CONSUMPTION IN MILLILITRES PER SECOND,  
 AND AVERAGE FORCE IN POUNDS PER SECOND  
 FOR ISOMETRIC CONTRACTION GROUP



with the pre-test, resulting in a decrease in Oxygen Consumption per pound-second. However, this trend did not follow for the post-test as there was a decrease in the Average Force to a value lower than the pre-test, and an increase in Oxygen Consumption to a value higher than the pre-test. These two fluctuations resulted in an increase in Oxygen Consumption per pound-second to a value higher than the pre-test. The isometric contraction group was the only one which did not consume less oxygen per pound-second in the post-test than in the pre-test.

### Discussion

Differences between Contraction Groups. Analysis of variance yielded a significant difference between contraction groups in Oxygen Consumption per pound-second which the Newman-Keuls test on row means indicated were all significant. Since the experimental leg dynamometer used in this study was unique in the sense that such testing and training techniques had not been used previously, comparisons with results of other studies had to be made with caution. However, the significant differences in oxygen consumption per pound-second between the eccentric and concentric contraction groups conformed with the results of Abbott, et.al. (3) and Asmussen (6) who tested subjects on especially designed bicycle ergometers.

In the present study, in terms of desirable performance, the eccentric contraction group performed best, followed by isometric and concentric groups for the three test periods. Abbott, et.al. (3) and Asmussen (6) concluded that negative work (eccentric muscular contractions) also cost less in terms of oxygen consumption than positive work (concentric muscular contractions). The studies reviewed did not encompass



the results of oxygen consumption for all three types of muscular contraction as was undertaken in this experiment. Therefore, the fact that isometric contractions at a knee angle of 110 degrees flexion required less in terms of Oxygen Consumption per pound-second than the concentric group, and more than the eccentric group, could not be substantiated by the literature reviewed.

The study by Abbott and Bigland (4), where force and speed were varied independently, and the article by Passmore and Durnin (34), which reported different types of activities where the legs were not isolated, were not inconsistent with the findings of this study. However, any comparison beyond such observation would have been unsound because methods and procedures were different. The significant differences found between concentric and isometric contraction groups did not disagree with the findings of Clarke (7) and Sharkey (14). Clarke (7) found that the Oxygen Consumption during static work was less than that required during dynamic work performed on a bicycle ergometer but there was a larger oxygen debt. Sharkey (14) compared static (isometric) and concentric contractions of the legs and found that Oxygen Consumption during the static contraction was less than that of the dynamic contraction. Again, the studies cited differed in methods and procedures from the present study so no further comparisons beyond this could be made.

Statistical analysis indicated significant differences between all contraction groups with respect to Average Force in pounds per second. There were no significant differences between contraction groups in Oxygen Consumption in millilitres per second.<sup>1</sup> These two aspects of the study were not discussed separately since their relationship with each

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<sup>1</sup>Probability was .11



other determined the final result in terms of Oxygen Consumption per pound-second.

Differences between Training Periods. Analysis of variance did not yield significant differences in Oxygen Consumption per pound-second, Average Force in pounds per second, or Oxygen Consumption in millilitres per second over the pre-, mid-, and post-test periods. The aspect of Average Force in pounds per second, which contributed to the overall result of Oxygen Consumption per pound-second, was worth special note and explanation. These results did not support the findings of other researchers (10, 11, 28, 35, 37) who used the large muscles of the leg for training studies. It was established by these researchers that training over a period of time resulted in an increase in strength. But the method of recording the data which determined a subject's strength was different for those studies than for the present study. Only the amplitude, or the average or singular "greatest effort" was used as the strength score in the studies cited. In this study, the entire force exerted by the subjects was recorded and averaged over the time of the contraction. Such a method differed greatly from those used in the cited studies so comparisons between the results of the two methods were not in order for this study.

However, further discussion as to why there was no significant increase in strength over the training period is in order. During a series of six-second contractions it is possible that subjects did not exert maximum muscular effort for the entire time period. This may have been the case during the training periods of the previously cited studies but during the actual tests for those studies, only the maximum peak



effort was recorded as the strength score. But, as previously stated, in this study the measurement of total force or impulse was divided by the total contraction time thereby reducing the value to Average Force in pounds per second. This inability to maintain maximum contraction over a time period, which might have been a physical or mental inability, is suggested as a reason why increases in strength over the training period did not result.

Interaction between Groups and Training Periods. Analysis of variance did not yield a significant difference in Oxygen Consumption per pound-second, Average Force in pounds per second, or Oxygen Consumption in millilitres per second. The effect of training, as measured by the three test periods, did not influence any of three contraction groups in a significantly different manner. Over the three tests, the three contraction groups maintained the same relationship with each other.

Limitations of the Study. Certain limitations of this study may have influenced the results of the differences in Oxygen Consumption per pound-second which were found to be between all contraction groups. There were two important variables inherent in this study which could not be made compatible with each other: the duration of a contraction and the range in knee angle of a contraction. Initially, a six-second time period was selected as the length of a single contraction because the speed of the leg dynamometer could be adjusted to enable an individual of average leg-length to move a range of ninety degrees of knee flexion in that time period. In this way it was expected to standardize the duration of the contraction. However, it was found that although the test administrator used six-seconds as a guide on a stop-



watch, it was necessary to extend that time during contractions of subjects in the eccentric and concentric groups in order to complete the desired range of movement. After a series of preliminary tests it was decided that subjects were to move through the entire range of movement and not adhere to the six-second time limit.<sup>2</sup> Appendix E shows the mean, standard deviation and range of the contraction times of the three groups over the three tests. Although the variation within each group and each test was great, neither the groups nor the tests were considered to be significantly different from each other on this criteria.

The cable of the leg dynamometer moved at a constant and uniform speed during eccentric and concentric contractions and, therefore, slight fluctuations in times of contractions were expected because of the slight differences in leg-length between subjects. Other variables which influenced the amount of mechanical and testing error were the difficulty of manipulating the controls used to set the cable length in the limited time available (fifteen seconds) between each contraction, and the slight bar-and-belt harness slippage following a series of muscular contractions of maximum effort.

The above consideration of two limitations may also account for some of the discrepancy and fluctuation in the duration of the contraction. Appendix B shows the contraction times and it appeared no group differed significantly from any other on this criteria. However, fluctuations

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<sup>2</sup> The fact that not all contractions were of six-second duration did not alter the total time of the active phase of the test (the time period during which expired air was collected in the second Douglas bag). A second test-administrator determined the total time period for this bag which was 1.85 minutes although it was certain that there was more than the originally proposed 36 seconds (six contractions of six-second duration each) of muscular contraction in the time period.



in range of movement did not appear in raw data because no objective device was used to record the actual range of movement of each contraction. As stated previously, the knee angles for the required contractions were checked for each subject prior to the five minutes of initial rest. No check was possible between contractions because the subject was required to remain in the rest position for as long as possible. For the actual contractions, however, the variables stated above affected the accuracy of the range of movement of ninety degrees, and determined whether the range was actually from 60 degrees to 150 degrees of flexion for the concentric group, or from 150 degrees to 60 degrees for the eccentric contraction group. It can only be stated that such a range of movement was the aim and objective throughout the test and it was not felt that this factor influenced the results in a biased manner, or to a great extent.

The above discussion of the duration of contraction and range of knee flexion concerns only the eccentric and concentric contraction groups. Although no movement was involved during contractions of the isometric group, and the proposed duration of the contraction was six-seconds, the results<sup>3</sup> showed that the overall time of each contraction was closer to seven-seconds. Such a result introduced a third variable which was present in all three contraction groups. Since the test administrator used a stop-watch to time the contraction and the times of the contractions were recorded on the dynograph as being consistently greater, it appeared that the subject did not respond or react in a consistent manner to the verbal signals made by the test administrator.

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<sup>3</sup>  
Appendix E



During the thirty-seconds before the first contraction, and then fifteen seconds for all subsequent contractions, the subject rested by sitting on the stool. Towards the end of these rest periods (with approximately three to four seconds remaining) the subjects were instructed to get ready for the ensuing contraction. To minimize the strain imposed upon the legs, the subjects were instructed to raise and support the weight of their bodies with their arms by grasping the rails on which the restraining belt moved.<sup>4</sup> It appeared that during this time the subjects were actually contracting and the force was recorded by the dynograph. When the dynograph charts were analyzed, all significant curves above the zero line were taken into account for the calculation of Average Force. The contraction time was considered to have begun at that point as well and this accounted, to some extent, for the excess in the duration of the contraction beyond the six-second period.

The previous discussion about the limitations of the study in respect to length of contraction time and range of movement applies to all facets of the study and not merely to the differences between the contraction groups.

There was a further factor which might have influenced the results of the difference between contraction groups and this involved the friction which was present during eccentric and concentric contractions. Although the vertical board which supported the subject during movement<sup>5</sup> was kept highly polished, friction was present. The

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<sup>4</sup>Item c, Figure 4, page 26.

<sup>5</sup>Item b, Figure 4, page 26.



extent of the effect of this friction varied between contraction groups. Subjects in the eccentric group commenced the contraction from a standing position with the angle of knee flexion being 150 degrees. The weight of the body against the backboard produced friction which assisted the subjects in this group to resist the downward pull by the cable. Conversely, the concentric group had the added task of overcoming friction since the muscular effort involved the lifting of the cable by extending the knee from an angle of 60 degrees flexion. For the isometric group it was estimated that the effect of friction was negligible since little movement was involved.

The extent and overall influence of this factor of friction was difficult to assess but the conclusion was made that it assisted the eccentric contraction group and made the task more difficult for the concentric group.

It was also considered that the effect of gravity may have influenced the results in a similar manner to that of friction. The concentric contraction group had to initiate and continue the movement in an upward direction, thus overcoming the force of gravity. Conversely, the eccentric contraction group, although they had to resist the force of gravity, did not have to initiate the movement because they were pulled downwards. It was felt that the effect of gravity was not as great for the isometric group as for the concentric group. As in the case of friction, the extent and overall influence of the gravitational factor was difficult to assess.



## CHAPTER V

### SUMMARY AND CONCLUSIONS

#### Summary

The purpose of this study was to determine the relationship between the oxygen consumption of concentric, eccentric, and isometric muscular contractions before, during and after a strength training programme.

A random sample of 33 freshman University of Alberta males participated in, and completed, the training and testing programme which lasted for nine weeks. Each subject trained as a member of the particular group to which he had been assigned and over the experimental period trained 18 times at an average of three times weekly. Subjects commenced training with six, six-second contractions per training session and increased this number by three after every third training session until a total of 18 contractions was reached.

During the tests the expired air of each subject was collected at various intervals to determine the oxygen consumed during a series of contractions and this value was converted into Oxygen Consumption in millilitres per second. The force exerted by each subject during contractions was recorded and converted into the value of Average Force in pounds per second. The above measurements were used to ascertain the value of Oxygen Consumption per pound-second.

A computerized programme of the two-way analysis of variance with repeated measures on one factor was used to test the hypotheses and the Newman-Keuls procedure for investigating row mean differences was



used where applicable.

### Conclusions

The following conclusions appear to be justified within the delimitations and limitations as previously outlined.

1. The means of the three contraction groups were shown not to be equal in respect to Oxygen Consumption per pound-second. The concentric, eccentric and isometric contraction groups differed significantly from each other with the eccentric contraction group requiring the least oxygen consumption per pound-second, the concentric group requiring the most and the isometric group requiring less than concentric and more than eccentric ( $P < 0.01$ ). The ratios of the row means for each contraction showed that the concentric contraction group consumed 2.6 and 1.9 times more oxygen per pound-second than the eccentric and isometric groups, respectively. The isometric group consumed 1.4 times more oxygen than the eccentric contraction group.

2. The means of the three periods were not shown to be significantly different from each other so the training programme did not significantly affect the Oxygen Consumption per pound-second of any group.

3. The interaction between the contraction groups and the test periods was not found to be significant in respect to Oxygen Consumption per pound-second.

Oxygen Consumption did not necessarily increase with an increase in strength, and this applied to all contraction groups.

In conclusion, the results indicated that the eccentric contraction training method was the most efficient of the three types of



contraction since it required the least amount in Oxygen Consumption per pound-second for the most amount in Average Force in pounds per second.

### Recommendations

Further research into the relationships between oxygen consumption and different types of muscular contraction is recommended. Special attention to standardizing the factors of friction and gravity should be given and this could be done by modifying the leg dynamometer used in this study so that subjects of all three contraction groups perform while in a horizontal position strapped to a movable base-board. This modification would also standardize the starting positions as the subjects of all groups could be placed into position for successive contractions by a test administrator, thus facilitating a period of complete rest for the subjects between contractions.

It is recommended for future studies in this field, that data with the strength aspect be collected in two forms: that of Average Force in pounds per second, as was done in the present study; and in the form of the singular maximum peak in each effort. In this way, a closer comparison with other strength studies could be made.



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## APPENDIX A

### ANTHROPOMETRICAL DATA



AGE, HEIGHT, WEIGHT, AND LEG LENGTH  
OF SUBJECTS IN CONCENTRIC, ECCENTRIC  
AND ISOMETRIC CONTRACTION GROUPS

Subject No.	Age (yrs)	Height (ins)	Weight (lbs)	Upper Leg (ins)	Lower Leg (ins)
CONCENTRIC (n = 10)					
2	23.2	72.25	165.0	16.5	18.0
4	20.6	69.0	153.0	16.25	17.0
5	19.8	67.25	123.0	14.5	15.75
6	18.3	68.25	156.0	15.0	16.25
7	17.9	68.5	141.5	14.5	16.0
8	17.9	66.0	172.0	14.0	15.5
10	18.3	70.0	139.0	16.0	16.5
11	17.7	70.75	136.0	16.75	17.5
12	19.1	68.25	131.0	16.75	17.0
13	18.8	72.5	174.5	17.5	17.75
ECCENTRIC (n=12)					
14	18.4	71.5	164.5	16.25	17.5
15	19.2	68.5	127.0	15.5	16.5
16	18.5	72.0	155.0	17.75	18.0
18	19.4	67.75	153.5	16.0	17.0
19	24.5	69.75	150.0	16.0	16.75
20	18.1	67.75	172.5	16.75	15.0
21	20.2	69.5	151.5	16.5	17.5
22	18.2	71.5	144.0	17.0	18.0
23	17.9	68.25	138.5	15.5	16.5
24	18.6	71.0	158.0	16.0	16.0
25	18.7	72.0	143.0	17.0	18.25
26	18.7	65.25	178.0	14.5	16.0
ISOMETRIC (n = 11)					
27	18.1	67.0	143.0	16.0	15.5
29	18.1	72.75	156.0	17.5	16.75
30	19.1	65.75	115.0	14.25	15.5
31	18.8	65.0	150.0	14.0	15.0
32	18.7	68.25	140.25	16.0	17.0
33	19.7	68.5	145.25	15.5	16.75
34	17.2	66.0	124.5	15.0	15.75
35	20.2	70.0	192.0	16.5	17.5
36	19.7	68.0	132.0	15.5	16.25
37	18.9	71.0	153.0	16.0	17.0
39	20.4	69.0	140.0	15.0	15.75



## APPENDIX B

### RAW SCORES



RAW SCORES FOR CONCENTRIC, ECCENTRIC AND  
ISOMETRIC CONTRACTION GROUPS: PRE-TEST

Subject	Total Force (lbs)	Contraction Time (secs)	Average force (lbs/sec)	Oxygen Consumption (milli- litres)	Oxygen Consumption (milli- litres/sec)	Oxygen Consumption (milli- litres/sec per lb/sec)
CONCENTRIC (n=10)						
2	6167.7	41.48	148.7	3409.8	82.2	.55
4	4774.2	38.32	124.6	2832.8	73.9	.59
5	6503.2	43.36	150.0	3154.7	72.8	.49
6	6787.1	35.68	190.2	2902.3	81.3	.43
7	7458.0	42.28	176.4	2661.7	63.0	.36
8	5548.4	35.84	159.3	3255.0	93.4	.59
10	8129.0	40.64	200.0	2590.2	63.7	.32
11	4180.6	37.96	110.1	2463.6	67.4	.59
12	4232.2	40.36	104.9	2735.6	67.8	.64
13	5212.9	31.80	137.9	2111.5	55.9	.41
ECCENTRIC (n=12)						
14	15793.5	38.70	408.1	2791.6	72.1	.18
15	20516.1	41.56	493.6	2680.9	64.5	.13
16	14400.0	44.48	323.7	3127.3	70.3	.22
18	22658.0	44.80	505.8	3125.2	69.8	.14
19	12953.5	41.96	300.1	2181.8	52.0	.17
20	16541.9	42.16	392.4	2082.0	144.3	.37
21	13496.7	41.72	323.5	2601.1	62.3	.14
22	20490.3	44.40	461.5	3557.0	80.1	.17
23	13703.2	49.24	349.2	4006.1	102.1	.29
24	17780.6	42.26	420.7	2086.3	49.4	.12
25	11767.7	44.92	262.0	2940.3	65.5	.25
26	11406.4	34.52	330.4	3348.5	97.0	.29
ISOMETRIC (n=11)						
27	11406.4	42.84	266.3	2342.2	54.7	.21
29	9580.6	40.10	238.9	1258.6	31.4	.13
30	10296.8	46.60	230.9	1827.4	41.0	.18
31	9522.6	34.36	277.1	3772.9	109.8	.40
32	14993.5	41.28	363.3	1326.2	32.1	.09
33	11251.6	42.72	263.4	3768.5	88.2	.33
34	8709.7	48.70	208.9	1123.6	26.9	.13
35	6348.4	41.72	152.2	3386.3	81.2	.53
36	8361.3	43.76	191.1	2600.6	59.4	.31
37	10374.2	46.96	220.1	3229.8	69.0	.31
39	14116.1	37.74	374.0	2731.8	72.4	.19



RAW SCORES FOR CONCENTRIC, ECCENTRIC, AND  
ISOMETRIC CONTRACTION GROUPS: MID-TEST

Subject	Total Force (lbs)	Contraction Time (secs)	Average Force (lbs/sec)	Oxygen Consumption (milli- litres)	Oxygen Consumption (milli- litres/sec)	Oxygen Consumption (milli- litres/sec per lb/sec
CONCENTRIC (n=10)						
2	6761.3	47.20	143.2	3528.3	74.8	.52
4	5574.2	45.08	123.7	3774.9	83.7	.68
5	9238.7	45.92	201.2	2674.5	58.2	.29
6	7071.0	36.92	150.7	3202.0	68.2	.45
7	8593.5	42.36	202.9	3842.9	90.7	.44
8	6245.1	40.68	153.5	3341.7	82.1	.53
10	8645.1	44.12	195.9	3396.6	77.0	.39
11	5780.6	44.88	128.8	3407.9	75.9	.59
12	6916.1	45.20	153.0	3205.8	70.9	.46
13	5574.2	47.48	117.4	3593.6	75.7	.64
ECCENTRIC (n=12)						
14	12929.0	42.52	334.1	2851.2	67.1	.20
15	16051.6	43.96	365.1	3514.2	80.0	.22
16	16748.4	46.76	358.2	3580.6	76.6	.21
18	17703.2	41.32	428.4	3638.9	88.1	.21
19	11432.2	34.08	335.5	1777.5	52.2	.16
20	14632.2	43.52	336.2	2155.7	49.5	.15
21	19122.5	50.12	381.5	3126.2	62.4	.16
22	16619.3	48.88	340.0	2991.0	61.2	.18
23	14322.6	42.60	336.2	2178.7	51.1	.15
24	15483.8	47.40	326.7	2131.0	47.4	.14
25	10400.0	46.24	224.9	1632.3	35.3	.16
26	20232.2	39.84	507.8	4011.9	100.7	.20
ISOMETRIC (n=11)						
27	11612.9	45.24	256.7	1726.9	38.2	.15
29	6864.5	42.16	162.8	2378.4	56.4	.34
30	10348.4	44.76	231.2	1755.6	39.2	.17
31	21935.4	42.32	518.3	2530.6	59.8	.11
32	8361.3	41.84	199.8	1934.9	46.2	.23
33	12077.4	42.92	252.0	3848.2	80.3	.31
34	11277.4	45.76	246.4	2722.5	59.4	.24
35	11251.6	40.88	275.2	2581.8	63.2	.23
36	22245.1	45.24	491.7	3009.5	66.5	.14
37	14503.2	46.80	309.9	3235.9	69.1	.22
39	11845.1	43.92	269.7	2751.9	64.1	.24



RAW SCORES FOR CONCENTRIC, ECCENTRIC, AND  
ISOMETRIC CONTRACTION GROUPS: POST-TEST

Subject	Total Force (lbs)	Contraction Time (secs)	Average Force (lbs/sec)	Oxygen Consumption (milli- litres)	Oxygen Consumption (milli- litres/sec)	Oxygen Consumption (milli- litres/sec per lb/sec)
CONCENTRIC (n=10)						
2	6761.3	47.20	143.2	3528.3	74.8	.52
4	5574.2	45.08	123.7	3774.9	83.7	.68
5	9238.7	45.92	201.2	2674.5	58.2	.29
6	7071.0	46.92	150.7	3202.0	68.2	.45
7	8593.5	42.36	202.9	3842.9	90.7	.44
8	6245.1	40.68	153.5	3341.7	82.1	.53
10	8645.1	44.12	195.9	3396.6	77.0	.39
11	5780.6	44.88	128.8	3407.9	75.9	.59
12	6916.1	45.20	153.0	3205.8	70.9	.46
13	5574.2	47.48	117.4	3593.6	75.7	.64
ECCENTRIC (n=12)						
14	17109.6	46.44	368.4	2241.3	48.3	.13
15	24000.0	47.12	509.3	2485.8	52.8	.10
16	16129.6	41.68	387.0	3070.1	73.7	.19
18	18993.5	45.56	416.9	2806.9	61.6	.15
19	13832.2	40.28	343.4	2281.2	56.6	.16
20	16077.4	42.92	374.6	2783.1	64.8	.17
21	17341.9	47.28	366.8	3407.7	72.1	.20
22	19922.5	45.96	433.5	3442.5	74.9	.17
23	17522.5	39.64	442.0	3066.6	77.4	.18
24	17651.6	52.52	336.1	3432.9	65.4	.19
25	20645.1	41.50	256.5	2714.0	65.4	.25
26	24593.5	42.16	583.3	2564.8	60.8	.10
ISOMETRIC (n=11)						
27	11380.6	46.86	244.0	2461.3	52.8	.22
29	7612.9	44.04	172.9	3258.5	74.0	.42
30	10245.1	43.12	237.6	2073.4	48.1	.20
31	13006.4	42.88	303.3	2775.4	64.7	.21
32	6012.9	44.08	136.4	2177.6	49.4	.36
33	11406.4	44.54	256.1	3577.4	80.3	.31
34	10425.4	47.32	220.3	1940.3	41.0	.19
35	7251.6	42.74	169.7	2489.3	58.3	.34
36	12051.6	41.56	290.0	2590.7	62.3	.21
37	8903.2	43.32	205.5	4805.0	110.9	.54
39	11122.6	42.16	263.8	2834.0	67.2	.25



## APPENDIX C

### GAS METER VOLUME CORRECTION



Gas Meter Volume Correction

The American Meter Company gas meter (model 802) was tested in reference to a Collins 120 - litre chain-compensated gasometer accepted as standard. From a regression analysis of collected data the equation  $Y = .968 X - 0.515$  was obtained. ("Y" represents the corrected ATPS volume, and "X" the volume indicated on the meter.)



APPENDIX D

GAS ANALYSIS COMPUTATION SHEET



GAS ANALYSIS COMPUTATION  
(OXYGEN CONSUMPTION)

TEST \_\_\_\_\_

SUBJECT \_\_\_\_\_

SUBJECT NUMBER \_\_\_\_\_

TRAINING GROUP \_\_\_\_\_

TEMP. \_\_\_\_\_

S.T.P.D. \_\_\_\_\_

BAROMETRIC PR. \_\_\_\_\_

DOUGLAS BAG ONE (RESTING: 2 minute collection)

$$\%O_{2E} = \text{_____} \times 2.5 = \text{_____}\% \quad \%CO_{2E} = \text{_____}$$

$$\%N_{2E} = 100 - \text{_____} \quad \%O_{2E} - \text{_____} \quad \%CO_{2E} = \text{_____}\%$$

$$VEATPS = .968 ( \text{_____} ) - .515 \text{ divided by } 2 = \text{_____} \text{ Litres/min.}$$

+.325 litres

$$V_{ESTPD} = \text{_____} (\text{Factor}) \times \text{_____} \text{ L/min.} = \text{_____} \text{ L/min.}$$

$$V_{ISTPD} = \text{_____} V_{ESTPD} \times \frac{\%N_{2E}}{79.04} = \text{_____} \text{ L/min.}$$

$$VO_2 \text{ CONSUMPTION} = ( \text{_____} V_{ISTPD} \times .2093 ) - ( \text{_____} V_{ESTPD} \times \text{_____} \%O_{2E} ) = \text{_____} \text{ L/min.}$$

$$VCO_2 \text{ PRODUCTION} = ( \text{_____} V_{ESTPD} \times \text{_____} \%CO_{2E} ) - ( \text{_____} V_{ISTPD} \times .03 ) = \text{_____} \text{ L/min.}$$

DOUGLAS BAG TWO (ACTIVITY: 1.85 minute collection)

$$\%O_{2E} = \text{_____} \times 2.5 = \text{_____}\% \quad \%CO_2 = \text{_____}$$

$$\%N_{2E} = 100 - \text{_____} \quad \%O_{2E} - \text{_____} \quad \%CO_{2E} = \text{_____}\%$$

$$VEATPS = .968 ( \text{_____} ) - .515 \text{ divided by } 2.25 = \text{Litres/min.} \text{_____}$$

+.325 litres

$$V_{ESTPD} = \text{_____} (\text{Factor}) \times \text{_____} \text{ L/min.} = \text{_____} \text{ L/min.}$$

$$V_{ISTPD} = \text{_____} V_{ESTPD} \times \frac{\%N_{2E}}{79.04} = \text{_____} \text{ L/min.}$$

$$VO_2 \text{ CONSUMPTION} = ( \text{_____} V_{ISTPD} \times .2093 ) - ( \text{_____} V_{ESTPD} \times \text{_____} \%O_{2E} ) = \text{_____} \text{ L/min.}$$

$$VCO_2 \text{ PRODUCTION} = ( \text{_____} V_{ESTPD} \times \text{_____} \%CO_{2E} ) - ( \text{_____} V_{ISTPD} \times .03 ) = \text{_____} \text{ L/min.}$$

DOUGLAS BAG THREE (RECOVERY : 5 minute collection)

$$\%O_{2E} = \text{_____} \times 2.5 = \text{_____}\% \quad \%CO_{2E} = \text{_____}$$

$$\%N_{2E} = 100 - \text{_____} \quad \%O_{2E} - \text{_____} \quad \%CO_{2E} = \text{_____}\%$$

$$VEATPS = .968 ( \text{_____} ) - .515 \text{ divided by } 5.0 = \text{_____} \text{ L/min.}$$

+.325 litres

$$V_{ESTPD} = \text{_____} (\text{Factor}) \times \text{_____} \text{ L/min.} = \text{_____} \text{ L/min.}$$

$$V_{ISTPD} = \text{_____} V_{ESTPD} \times \frac{\%N_{2E}}{79.04} = \text{_____} \text{ L/min.}$$

$$VO_2 \text{ CONSUMPTION} = ( \text{_____} V_{ISTPD} \times .2093 ) - ( \text{_____} V_{ESTPD} \times \text{_____} \%O_{2E} ) = \text{_____} \text{ L/min.}$$

$$VCO_2 \text{ PRODUCTION} = ( \text{_____} V_{ESTPD} \times \text{_____} \%CO_{2E} ) - ( \text{_____} V_{ISTPD} \times .03 ) = \text{_____} \text{ L/min.}$$



## APPENDIX E

MEAN, STANDARD DEVIATION AND RANGE OF CONTRACTION TIME (SECONDS).



MEAN, STANDARD DEVIATION AND RANGE OF  
CONTRACTION TIME (SECONDS) FOR CONCENTRIC,  
ECCENTRIC AND ISOMETRIC CONTRACTION GROUPS  
FOR THE PRE-, MID-, AND POST-TESTS

Parameter	Mean	Standard Deviation	Range
Concentric - Pre-Test	39.3	2.7	34.84 - 43.36
Concentric - Mid-Test	45.0	2.0	42.36 - 47.48
Concentric - Post-Test	45.4	1.6	42.48 - 47.76
Eccentric - Pre-Test	42.6	3.5	34.52 - 49.24
Eccentric - Mid-Test	43.9	4.2	34.08 - 50.12
Eccentric - Post-Test	44.4	3.6	39.64 - 52.52
Isometric - Pre-Test	42.4	4.0	34.36 - 48.70
Isometric - Mid-Test	44.3	2.1	40.88 - 47.92
Isometric - Post-Test	43.9	1.7	41.56 - 47.32



## APPENDIX F

### COMPENSATING PLANIMETER



Use of Compensating Planimeter for Calculation of Average Force in pounds per second.

From the graphic representation recorded on the Beckman Type RS Dynograph which was calibrated to move one millimetre for every 100 pounds tension on the load cell, a Coradi compensating planimeter was used to measure the area beneath the curve. The recording chart of the Beckman Dynograph was used in preference to that of the Sargent Recorder (Model SR) because the former had a paper speed of 25 millimetres per second which produced an area of greater size than that of the latter instrument.<sup>1</sup>

A Coradi Compensating Planimeter (Type Cora - Senior) with adjustable tracing and pole arms was used to calculate the area beneath the curve recorded on the instrument paper of the dynograph. Calibration of the planimeter was checked by using the calibrating ruler to trace a series of circles. Over twenty tracings, the operator recorded readings which were always within the range of plus or minus five vernier units which was the admissible tolerance allowed by the manufacturer of the instrument. A further reliability test was administered by taking fifteen tracings of the curve of one subject during a contraction and, again, all scores were within the admissible tolerance limits. During the computation of the areas under the curve for all subjects over the three tests, two readings were taken. Where the readings differed by greater than the admissible tolerance limits, further readings were taken.

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<sup>1</sup>The paper speed of the Sargent Recorder Model SR was calculated as being 0.8333 millimetres per second.



The total areas for all six contractions of the subjects were converted from square inches (as recorded by the planimeter) to square millimetres.<sup>2</sup> From the calibration of the dynograph and load cell it was determined that 1 sq. mm. is equal to 4 pound-seconds so the area in square millimetres was multiplied by 4 to render the value as Total Force in pound-seconds.

The base or zero line of the Dynograph curve was used to determine actual contraction time since the paper-speed was constant at 25 millimetres per second. The length of the contraction in seconds was used as the denominator to determine the Average Force in pounds per second.

$$\text{e.g. Average Force} = \frac{\text{Total Force in pound-seconds}}{\text{Length of Contraction in Seconds}}$$

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<sup>2</sup>  
1 square inch = 645.16 square millimetres.









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